



08/31/00

09-01-20

EXPRESS MAILING LABEL NO: EL327517295US

BOX PATENT APPLICATION  
Assistant Commissioner for Patents  
Washington, D.C. 20231

Date: August 31, 2000  
Atty Docket No: 102689-51/00-U0075

Sir:

Transmitted herewith for filing is the patent application of:

Inventor(s): **Darryl Black and Kevin D. Snow**  
Entitled: **NETWORK MANAGEMENT SYSTEM INCLUDING CUSTOM SCREEN MARKS**



Enclosed are:

- ☒ Patent application (including 199 sheets of Specification; 2 sheets of Claims (Claims #1-16); 1 sheet of Abstract; and 146 sheets of ☒ informal ☐ formal drawings (one set) (**FIGS. 1, 2a-2b, 3a-3m, 4a-4z, 5a-5z, 6a-6p, 7a-7j, 8a-8c, 9a-9c, 10-15, 16a-16d, 17-30, 31a, 32a, 33a-33d, 34a, 34b, 35-40, 41a-41c, 42-58**);
- ☒ Title Sheet for Patent Application;
- ☒ Declaration and Power of Attorney (☒ executed ☐ unexecuted);
- ☒ Verified Statement Claiming Small Entity Status;
- ☐ Information Disclosure Statement (w/Form PTO-1449 and copies of referenced documents);
- ☒ Assignment (w/Recordation Cover Sheet) of the invention to **Équipe Communications Corporation**;
- ☒ Check in the amount of **\$40.00** representing Assignment Recordal Fee;
- ☒ Check in the amount of **\$345.00** representing filing fee based on  
☐ large entity status ☒ small entity status;
- ☒ Bibliographic Data Sheet; and
- ☒ Postcard receipt.

CLAIMS FILED:	MINUS BASE:	EQUALS EXTRA CLAIMS:	RATE:	BASIC FEE \$ 690.00
Total: 16	20	0	x \$ 18.00	\$ 0.00
Independent: 3	3	0	x \$ 78.00	\$ 0.00
Multiple Dependent Claims (1st presentation)			\$260.00	\$ 0.00
SUBTOTAL FILING FEE				\$ 690.00
Small Entity filing, divide by 1/2 (Note: Verified Statement must be attached)				\$
TOTAL FILING FEE				\$ 345.00

- ☒ The Commissioner is hereby authorized to charge payment of any additional filing fees under §1.16 associated with this communication or credit any overpayment to Deposit Account No. 141449.

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**EXPRESS MAILING LABEL NO. EL327517295US**

**IN THE UNITED STATES PATENT AND TRADEMARK OFFICE**

**APPLICANT:** Black, et al.

**ATTORNEY DOCKET NO: 102689-51/00-UD075**

**APPLICATION NO: N/A**

**EXAMINER:** Not Yet Assigned

**FILED: Herewith**

**GROUP NO:** Not Yet Assigned

**ENTITLED:** Network Management System Including Custom Screen Marks

Assistant Commissioner for Patents  
Washington, D.C. 20231

### **STATEMENT CLAIMING SMALL ENTITY STATUS**

**Sir:**

**THE UNDERSIGNED STATES:**

Exclusive rights in the above-identified invention reside in the "small entity(ies)" defined and named below, and "small entity" fees are appropriate. Qualification as a small entity is based upon the statement(s) below:

## SMALL BUSINESS CONCERN

The below-identified small business concern qualifies as a small business as defined in 13 C.F.R. § 121.3-18, and reproduced in 37 C.F.R. § 1.9(d), for purposes of paying reduced fees under Sections 41(a) and (b) of Title 35, in that the number of employees, including those of its affiliates, which does not exceed 500 persons, and it has not assigned, granted, conveyed or licensed, and is under no obligation under contract or law to assign, grant, convey or license, any rights in the invention to any person who could not be classified as an independent inventor if that person had made the invention, or to any concern which would not qualify as a small business concern under 37 C.F.R. § 1.9(d) or a nonprofit organization under 37 C.F.R. § 1.9(e).

Concerns are affiliates of each other when, either directly or indirectly, one concern controls or has the power to control the other, or a third party controls or has the power to control both. The number of employees of the business concern is the average over the fiscal year of the persons employed during each of the pay periods of the fiscal year. Employees are those persons employed on a full-time, part-time or temporary basis during the previous fiscal year of the concern.

The undersigned acknowledge(s) the duty to file, in this application or patent, notification of any change in status resulting in loss of entitlement to small entity status prior to paying, or at the time of paying, the earliest of the issue fee or any maintenance fee due after the date on which status as a small entity is no longer appropriate (37 C.F.R. § 11.28(b)).

The below-signing individual(s) hereby declare(s) that (he, she, they) are authorized to execute this statement on behalf of the small entity; that all statements made herein of (his, her, their) own knowledge are true and that all

[illegible]

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statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code, and that such willful false statements may jeopardize the validity of the application, any patent issue thereon, or any patent to which this verified statement is directed.

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Name of Small Entity:

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Equipe Communications Corporation

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Address of Small Entity:

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One Hundred Nagog Park, Acton, MA 01720

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Name of Person Signing:

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Patricia Davis

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Title of Person Signing:

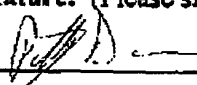
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Corporate Counsel

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Signature: (Please sign and date in permanent ink.)

X



Date signed:

X

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Table 1. Characteristics of the study population	
Number of subjects	100
Age (years)	50.0 ± 10.0
Weight (kg)	70.0 ± 15.0
Height (cm)	170.0 ± 5.0
Body mass index (kg/m <sup>2</sup> )	24.0 ± 3.0
Smoking status	
Smokers	40 (40%)
Nonsmokers	60 (60%)
Alcohol consumption (g/day)	20.0 ± 10.0
Physical activity (MET-h/week)	10.0 ± 5.0
Family history of CHD	
Yes	30 (30%)
No	70 (70%)
Diabetes mellitus	
Yes	10 (10%)
No	90 (90%)
Hypertension	
Yes	20 (20%)
No	80 (80%)
Previous MI	
Yes	5 (5%)
No	95 (95%)
Current medications	
Beta-blockers	10 (10%)
Calcium antagonists	15 (15%)
Diuretics	20 (20%)
Nitroglycerin	5 (5%)
Other	10 (10%)
None	45 (45%)

CORRESPONDENCE INFORMATION

APPLICATION INFORMATION

REPRESENTATIVE INFORMATION

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Representative Customer Number:: 21125
Registration Number One:: 38403
Registration Number Two:: 32675
Registration Number Three:: 28711
Registration Number Four:: 30833
Registration Number Five:: 31359
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Registration Number Six:: 44238  
Registration Number Seven:: 43810  
Registration Number Eight:: 31868  
Registration Number Nine:: 45053  
Registration Number Ten:: 41277  
Registration Number Eleven:: 43328

# CONTINUITY INFORMATION

This application is a:: CONTINUATION IN PART OF  
> Application One:: 09/637/800  
Filing Date:: 08-11-2000

Source:: PrintEFS Version 1.0.1

00T500" 5T5T5050

APPLICATION  
FOR  
UNITED STATES LETTERS PATENT

TITLE OF INVENTION

NETWORK MANAGEMENT SYSTEM INCLUDING CUSTOM SCREEN MARKS

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EXPRESS MAILING LABEL NO.: **EL327517295US**

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**NETWORK MANAGEMENT SYSTEM INCLUDING  
CUSTOM SCREEN MARKS**

This application is a continuation-in-part of U.S. Serial Number \_\_\_\_\_, filed August 11, 2000, entitled "Processing Network Management Data In Accordance With Metadata Files", still pending.

**Background**

A typical network / element management system (NMS) allows a network manager to select a particular network device to manage and then provides a graphical user interface (GUI) that the network manager may use to configure the network device. For instance, the network manager may wish to configure a logical Asynchronous Transfer Mode (ATM) interface on a particular network device port. Generally, the network manager begins by selecting the physical port and selecting an "add ATM interface" feature. This usually causes the GUI to display a dialog box into which the network manager enters the parameters associated with this particular ATM interface.

For each ATM interface, the same series of steps must be repeated, and for other configuration tasks other series of steps must be repeated. The GUI provides static choices and is not flexible. That is, the screen flow provided by the GUI is predetermined and the network manager must walk through a predetermined set of screens each time a resource is configured. In addition, the network manager is limited as to which screens may be seen simultaneously, and to reach certain screens, one or more other screens may have to be sequenced through first. Dialog modality, for example, may preclude a network manager from viewing more than one dialog box at a time. Thus, configuring an entire network device is labor intensive and may take considerable time.

Moreover, many configuring / provisioning tasks, such as configuring ATM interfaces, require expert knowledge. The network manager must know of all the possible parameters available and then select the appropriate parameters for the task at hand. A large number of parameters in a complex network device may easily lead to a mis-configuration. Certain mis-configurations may violate system, protocol or other constraints rendering the configuration invalid and unusable. Other mis-configurations may lead to network device errors or a network device or network crash.

A few currently available network management systems allow a network manager to prepare some initial configuration data prior to connecting a new network device into a network. Since this configuration data is in a different format than the configuration data stored within the network device, only a portion of the configuration data may be prepared ahead of time. In addition, the partial configuration data must be translated prior to being sent to the network device, and translation errors may lead to data corruption or data merge problems. Moreover, the partial configuration data is typically passed to the network device using Simple Network Management Protocol (SNMP) over an unreliable User Datagram Protocol (UDP) connection. Such a data transfer may take a considerable amount of time, and an error in such a data transfer may lead to a commitment of an invalid partial configuration within the network device. In addition, in the event of an invalid translation, the device may be set up with erroneous configuration records.

### **Summary**

To simplify network device configuration tasks and provide configuration flexibility and efficiency, the present invention includes a custom navigator tool. Through the custom navigator tool, a network manager may select various screen marks each of which causes the custom navigator tool to shortcut the configuration process by jumping forward past various configuration screens to a particular configuration screen corresponding to the screen mark. The screen marks may be default screen marks provided as a standard part of a network management system graphical user interface (GUI) and/or the screen marks

may be custom screen marks created by the network manager. To create a custom screen mark the network manager simply accesses a desired GUI screen and selects a screen mark option. The custom navigator tool then requests a screen mark name from the network manager and, once provided, lists the custom screen mark name in an inventory of available screen mark names. When the network manager selects a screen mark name (custom or default), the custom navigator tool jumps to the corresponding GUI screen. As a result, the custom navigator tool allows a network manager to customize the GUI and, thus, make their provisioning tasks more efficient. The screen marks provide configuration short cuts that may simplify the configuration process and save the administrator configuration time.

In one aspect, the present invention provides a method of managing a telecommunications network including presenting a graphical user interface (GUI) to a user, including providing a plurality of screen marks, and jumping to a GUI screen corresponding to a first one of the plurality of screen marks in response to the user's selection of the first screen mark. The method may also include jumping to a GUI screen corresponding to a second one of the plurality of screen marks in response to the user's selection of the second screen mark. Providing a plurality of screen marks may include displaying the screen marks in a pull-down menu, and at least one of the screen marks may be a default screen mark and/or a custom screen mark.

In another aspect, the present invention provides a network management system including a graphical user interface (GUI) including a custom navigator tool. The GUI may also include multiple screen marks, and at least one of the screen marks may be a default screen mark and/or a custom screen mark.

In yet another aspect, the present invention provides a method of managing a telecommunications network including displaying a graphical user interface (GUI) screen in response to input from a user, receiving a screen mark selection from the user and creating a custom screen mark in response to the screen mark selection. After receiving a screen mark selection from the user, the method may include prompting the user to input

a screen mark name and receiving a screen mark name from the user, and creating a custom screen mark in response to the screen mark selection may include naming the custom screen mark with the screen mark name received from the user. The method may also include displaying the custom screen mark, which may include listing the custom screen mark in a pull down menu. The pull down menu may also lists other screen marks, and at least one of the other screen marks may be a default screen mark. The method may further include detecting a selection of the custom screen mark by the user and jumping to the GUI screen corresponding to the custom screen mark.

### **Brief Description of the Drawings**

Fig. 1 is a block diagram of a computer system with a distributed processing system;  
Figs. 2a-2b are block and flow diagrams of a distributed network management system;  
Fig. 3a is a block diagram of a logical system model;  
Figs. 3b and 3d-3f are flow diagrams depicting a software build process using a logical system model;  
Fig. 3c is a flow diagram illustrating a method for allowing applications to view data within a database;  
Fig. 3g is a flow diagram depicting a configuration process;  
Figs. 3h and 3j are flow diagrams depicting template driven network services provisioning processes;  
Figs. 3i and 3k-3m are screen displays of an OSS client and various templates;  
Figs. 4a-4z, 5a-5z, 6a-6p and 7a-7j are screen displays of graphical user interfaces;  
Figs. 8a and 9a are block and flow diagrams of a computer system incorporating a modular system architecture and illustrating a method for accomplishing hardware inventory and setup;  
Figs. 8b, 8c, 10, 11a, 11b, 12, 13 and 14 are tables representing data in a configuration database;  
Fig. 9b is a block and flow diagram of a computer system incorporating a modular system architecture and illustrating a method for configuring the computer system using a network management system;

Fig. 9c is a block and flow diagram of an accounting subsystem for pushing network device statistics to network management system software;

Fig. 15 is a block and flow diagram of a line card and a method for executing multiple instances of processes;

Figs. 16a-16b are flow diagrams illustrating a method for assigning logical names for inter-process communications;

Fig. 16c is a block and flow diagram of a computer system incorporating a modular system architecture and illustrating a method for using logical names for inter-process communications:

Fig. 16d is a chart representing a message format;

Figs. 17-19 are block and flow diagrams of a computer system incorporating a modular system architecture and illustrating methods for making configuration changes;

Fig. 20 is a block and flow diagram of a computer system incorporating a modular system architecture and illustrating a method for distributing logical model changes to users;

Fig. 21 is a block and flow diagram of a computer system incorporating a modular system architecture and illustrating a method for making a process upgrade;

Fig. 22 is a block diagram representing a revision numbering scheme;

Fig. 23 is a block and flow diagram of a computer system incorporating a modular system architecture and illustrating a method for making a device driver upgrade;

Fig. 24 is a block diagram representing processes within separate protected memory blocks;

Fig. 25 is a block and flow diagram of a line card and a method for accomplishing vertical fault isolation:

Fig. 26 is a block and flow diagram of a computer system incorporating a hierarchical and configurable fault management system and illustrating a method for accomplishing fault escalation.

Fig. 27 is a block diagram of an application having multiple sub-processes;

Fig. 28 is a block diagram of a hierarchical fault descriptor;

Fig. 29 is a block and flow diagram of a computer system incorporating a distributed redundancy architecture and illustrating a method for accomplishing distributed software redundancy;

Fig. 30 is a table representing data in a configuration database;

Figs. 31a-31c, 32a-32c, 33a-33d and 34a-34b are block and flow diagrams of a computer system incorporating a distributed redundancy architecture and illustrating methods for accomplishing distributed redundancy and recovery after a failure;

Fig. 35 is a block diagram of a network device;

Fig. 36 is a block diagram of a portion of a data plane of a network device;

Fig. 37 is a block and flow diagram of a network device incorporating a policy provisioning manager;

Figs. 38 and 39 are tables representing data in a configuration database;

Fig. 40 is an isometric view of a network device;

Figs. 41a-41c are front, back and side block diagrams, respectively, of components and modules within the network device of Fig. 40;

Fig. 42 is a block diagram of dual mid-planes;

Fig. 43 is a block diagram of two distributed switch fabrics and a central switch fabric;

Fig. 44 is a block diagram of the interconnections between switch fabric central timing subsystems and switch fabric local timing subsystems;

Fig. 45 is a block diagram of a switch fabric central timing subsystem;

Fig. 46 is a state diagram of master / slave selection for switch fabric central timing subsystems;

Fig. 47 is a block diagram of a switch fabric local timing subsystem;

Fig. 48 is a state diagram of reference signal selection for switch fabric local timing subsystems;

Fig. 49 is a block diagram of the interconnections between external central timing subsystems and external local timing subsystems;

Fig. 50 is a block diagram of an external central timing subsystem;

Fig. 51 is a timing diagram of a first timing reference signal with an embedded second timing signal;

Fig. 52 is a block diagram of an embeddor circuit;

Fig. 53 is a block diagram of an extractor circuit;

Fig. 54 is a block diagram of an external local timing subsystem;

Fig. 55 is a block diagram of an external central timing subsystem;



Fig. 56 is a block diagram of a network device connected to test equipment through programmable physical layer test ports;

Fig. 57 is a block and flow diagram of a network device incorporating programmable physical layer test ports; and

Fig. 58 is a block diagram of a test path table.

### Detailed Description

A modular software architecture solves some of the more common scenarios seen in existing architectures when software is upgraded or new features are deployed. Software modularity involves functionally dividing a software system into individual modules or processes, which are then designed and implemented independently. Inter-process communication (IPC) between the processes is carried out through message passing in accordance with well-defined application programming interfaces (APIs) generated from the same logical system model using the same code generation system. A database process is used to maintain a primary data repository within the computer system / network device, and APIs for the database process are also generated from the same logical system model and using the same code generation system ensuring that all the processes access the same data in the same way. Another database process is used to maintain a secondary data repository external to the computer system / network device; this database receives all of its data by exact database replication from the primary database.

A protected memory feature also helps enforce the separation of modules. Modules are compiled and linked as separate programs, and each program runs in its own protected memory space. In addition, each program is addressed with an abstract communication handle, or logical name. The logical name is location-independent; it can live on any card in the system. The logical name is resolved to a physical card/process during communication. If, for example, a backup process takes over for a failed primary process, it assumes ownership of the logical name and registers its name to allow other processes to re-resolve the logical name to the new physical card/process. Once

complete, the processes continue to communicate with the same logical name, unaware of the fact that a switchover just occurred.

Like certain existing architectures, the modular software architecture dynamically loads applications as needed. Beyond prior architectures, however, the modular software architecture removes significant application dependent data from the kernel and minimizes the link between software and hardware. Instead, under the modular software architecture, the applications themselves gather necessary information (i.e., metadata and instance data) from a variety of sources, for example, text files, JAVA class files and database views, which may be provided at run time or through the logical system model.

Metadata facilitates customization of the execution behavior of software processes without modifying the operating system software image. A modular software architecture makes writing applications – especially distributed applications – more difficult, but metadata provides seamless extensibility allowing new software processes to be added and existing software processes to be upgraded or downgraded while the operating system is running. In one embodiment, the kernel includes operating system software, standard system services software and modular system services software. Even portions of the kernel may be hot upgraded under certain circumstances. Examples of metadata include, customization text files used by software device drivers; JAVA class files that are dynamically instantiated using reflection; registration and deregistration protocols that enable the addition and deletion of software services without system disruption; and database view definitions that provide many varied views of the logical system model. Each of these and other examples are described below.

The embodiment described below includes a network computer system with a loosely coupled distributed processing system. It should be understood, however, that the computer system could also be a central processing system or a combination of distributed and central processing and either loosely or tightly coupled. In addition, the computer system described below is a network switch for use in, for example, the Internet, wide area networks (WAN) or local area networks (LAN). It should be

understood, however, that the modular software architecture can be implemented on any network device (including routers) or other types of computer systems and is not restricted to a network switch.

A distributed processing system is a collection of independent computers that appear to the user of the system as a single computer. Referring to Fig. 1, computer system 10 includes a centralized processor 12 with a control processor subsystem 14 that executes an instance of the kernel 20 including master control programs and server programs to actively control system operation by performing a major portion of the control functions (e.g., booting and system management) for the system. In addition, computer system 10 includes multiple line cards 16a-16n. Each line card includes a control processor subsystem 18a-18n, which runs an instance of the kernel 22a-22n including slave and client programs as well as line card specific software applications. Each control processor subsystem 14, 18a-18n operates in an autonomous fashion but the software presents computer system 10 to the user as a single computer.

Each control processor subsystem includes a processor integrated circuit (chip) 24, 26a-26n, for example, a Motorola 8260 or an Intel Pentium processor. The control processor subsystem also includes a memory subsystem 28, 30a-30n including a combination of non-volatile or persistent (e.g., PROM and flash memory) and volatile (e.g., SRAM and DRAM) memory components. Computer system 10 also includes an internal communication bus 32 connected to each processor 24, 26a-26n. In one embodiment, the communication bus is a switched Fast Ethernet providing 100Mb of dedicated bandwidth to each processor allowing the distributed processors to exchange control information at high frequencies. A backup or redundant Ethernet switch may also be connected to each board such that if the primary Ethernet switch fails, the boards can fail-over to the backup Ethernet switch.

In this example, Ethernet 32 provides an out-of-band control path, meaning that control information passes over Ethernet 32 but the network data being switched by computer system 10 passes to and from external network connections 31a-31xx over a separate data

path 34. External network control data is passed from the line cards to the central processor over Ethernet 32. This external network control data is also assigned a high priority when passed over the Ethernet to ensure that it is not dropped during periods of heavy traffic on the Ethernet.

In addition, another bus 33 is provided for low level system service operations, including, for example, the detection of newly installed (or removed) hardware, reset and interrupt control and real time clock (RTC) synchronization across the system. In one embodiment, this is an Inter-IC communications (I<sup>2</sup>C) bus.

Alternatively, the control and data may be passed over one common path (in-band).

#### Network/Element Management System (NMS):

Exponential network growth combined with continuously changing network requirements dictates a need for well thought out network management solutions that can grow and adapt quickly. The present invention provides a massively scalable, highly reliable comprehensive network management system, intended to scale up (and down) to meet varied customer needs.

Within a telecommunications network, element management systems (EMSs) are designed to configure and manage a particular type of network device (e.g., switch, router, hybrid switch-router), and network management systems (NMSs) are used to configure and manage multiple heterogeneous and/or homogeneous network devices. Hereinafter, the term “NMS” will be used for both element and network management systems. To configure a network device, the network administrator uses the NMS to provision services. For example, the administrator may connect a cable to a port of a network device and then use the NMS to enable the port. If the network device supports multiple protocols and services, then the administrator uses the NMS to provision these as well. To manage a network device, the NMS interprets data gathered by programs running on each network device relevant to network configuration, security, accounting, statistics, and fault logging and presents the interpretation of this data to the network

administrator. The network administrator may use this data to, for example, determine when to add new hardware and/or services to the network device, to determine when new network devices should be added to the network, and to determine the cause of errors.

Preferably, NMS programs and programs executing on network devices perform in expected ways (i.e., synchronously) and use the same data in the same way. To avoid having to manually synchronize all integration interfaces between the various programs, a logical system model and associated code generation system are used to generate application programming interfaces (APIs) – that is integration interfaces / integration points -- for programs running on the network device and programs running within the NMS. In addition, the APIs for the programs managing the data repositories (e.g., database programs) used by the network device and NMS programs are also generated from the same logical system model and associated code generation system to ensure that the programs use the data in the same way. Further, to ensure that the NMS and network device programs for managing and operating the network device use the same data, the programs, including the NMS programs, access a single data repository for configuration information, for example, a configuration database within the network device.

Referring to Fig. 2a, in the present invention, the NMS 60 includes one or more NMS client programs 850a-850n and one or more NMS server programs 851a-851n. The NMS client programs provide interfaces for network administrators. Through the NMS clients, the administrator may configure multiple network devices (e.g., computer system 10, Fig. 1; network device 540, Fig. 35). The NMS clients communicate with the NMS servers to provide the NMS servers with configuration requirements from the administrator. In addition, the NMS server provides the NMS client with network device management information, which the client then makes available to the administrator. “Pushing” data from a server to multiple clients synchronizes the clients with minimal polling. Reduced polling means less management traffic on the network and more device CPU cycles available for other management task. Communication between the NMS client and server is done via Remote Method Invocation (RMI) over Transmission Control Protocol (TCP), a reliable protocol that ensures no data loss.

The NMS client and server relationship prevents the network administrator from directly accessing the network device. Since several network administrators may be managing the network, this mitigates errors that may result if two administrators attempt to configure the same network device at the same time.

The present invention also includes a configuration relational database 42 within each network device and an NMS relational database 61 external to the network device. The configuration database program may be executed by a centralized processor card or a processor on another card (e.g., 12, Fig. 1; 542, Fig. 35) within the network device, and the NMS database program may be executed by a processor within a separate computer system (e.g., 62, Fig. 9a). The NMS server stores data directly in the configuration database via JAVA Database Connectivity (JDBC) over TCP, and using JDBC over TCP, the configuration database, through active queries, automatically replicates any changes to NMS database 61. By using JDBC and a relational database, the NMS server is able to leverage database transactions, database views, database journaling and database backup technologies that help provide unprecedented system availability. Relational database technology also scales well as it has matured over many years. An active query is a mechanism that enables a client to post a blocked SQL query for asynchronous notification by the database when data changes are made after the blocked SQL query was made.

Similarly, any configuration changes made by the network administrator directly through console interface 852 are made to the configuration database and, through active queries, automatically replicated to the NMS database. Maintaining a primary or master repository of data within each network device ensures that the NMS and network device are always synchronized with respect to the state of the configuration. Replicating changes made to the primary database within the network device to any secondary data repositories, for example, NMS database 61, ensures that all secondary data sources are quickly updated and remain in lockstep synchronization.

Instead of automatically replicating changes to the NMS database through active queries, only certain data, as configured by the network administrator, may be replicated.

Similarly, instead of immediate replication, the network administrator may configure periodic replication. For example, data from the master embedded database (i.e., the configuration database) can be uploaded daily or hourly. In addition to the periodic, scheduled uploads, backup may be done anytime at the request of the network administrator.

Referring again to Fig. 2a, for increased availability, the network device may include a backup configuration database 42' maintained by a separate, backup centralized processor card (e.g., 12, Fig. 1; 543, Fig. 35). Any changes to configuration database 42 are replicated to backup configuration database 42'. If the primary centralized processor card experiences a failure or error, the backup centralized processor card may be switched over to become the primary processor and configuration database 42' may be used to keep the network device operational. In addition, any changes to configuration database 42 may be written immediately to flash persistent memory 853 which may also be located on the primary centralized processor card or on another card, and similarly, any changes to backup configuration database 42' may be written immediately to flash persistent memory 853' which may also be located on the backup centralized processor card or another card. These flash-based configuration files protect against loss of data during power failures. In the unlikely event that all copies of the database within the network device are unusable, the data stored in the NMS database may be downloaded to the network device.

Instead of having a single central processor card (e.g., 12, Fig. 1; 543, Fig. 35), the external control functions and the internal control functions may be separated onto different cards as described in U.S. Patent Application Serial Number \_\_\_, filed May 20, 2000 and entitled “Functional Separation of Internal and External Controls in Network Devices”, which is hereby incorporated herein by reference. As shown in Fig. 41a, the chassis may support internal control (IC) processor cards 542a and 543a and external control (EC) processor cards 542b and 543b. In this embodiment, configuration database

42 may be maintained by a processor on internal control processor card 542a and configuration database 42' may be maintained by a processor on internal control processor card 543a, and persistent memory 853 may be located on external control processor card 542b and persistent memory 853' may be located on external control processor card 543b. This increases inter-card communication but also provides increased fault tolerance.

The file transfer protocol (FTP) may provide an efficient, reliable transport out of the network device for data intensive operations. Bulk data applications include accounting, historical statistics and logging. An FTP push (to reduce polling) may be used to send accounting, historical statistics and logging data to a data collector server 857, which may be a UNIX server. The data collector server may then generate network device and/or network status reports 858a-858n in, for example, American Standard Code for Information Interchange (ASCII) format and store the data into a database or generate Automatic Message Accounting Format (AMA/BAF) outputs.

Selected data stored within NMS database 61 may also be replicated to one or more remote/central NMS databases 854a-854n, as described below. NMS servers may also access network device statistics and status information stored within the network device using SNMP (multiple versions) traps and standard Management Information Bases (MIBs and MIB-2). The NMS server augments SNMP traps by providing them over the conventional User Datagram Protocol (UDP) as well as over Transmission Control Protocol (TCP), which provides reliable traps. Each event is generated with a sequence number and logged by the data collector server in a system log database for in place context with system log data. These measures significantly improve the likelihood of responding to all events in a timely manner reducing the chance of service disruption.

The various NMS programs – clients, servers, NMS databases, data collector servers and remote NMS databases – are distributed programs and may be executed on the same computer or different computers. The computers may be within the same LAN or WAN or accessible through the Internet. Distribution and hierarchy are fundamental to making



any software system scale to meet larger needs over time. Distribution reduces resource locality constraints and facilitates flexible deployment. Since day-to-day management is done in a distributed fashion, it makes sense that the management software should be distributed. Hierarchy provides natural boundaries of management responsibility and minimizes the number of entities that a management tool must be aware of. Both distribution and hierarchy are fundamental to any long-term management solution. The client server model allows for increased scalability as servers and clients may be added as the number of network managers increase and as the network grows.

The various NMS programs may be written in the JAVA programming language to enable the programs to run on both Windows/NT and UNIX platforms, such as Sun Solaris. In fact the code for both platforms may be the same allowing consistent graphical interfaces to be displayed to the network administrator. In addition to being native to JAVA, RMI is attractive as the RMI architecture includes (RMI) over Internet Inter-Orb Protocol (IIOP) which delivers Common Object Request Broker Architecture (CORBA) compliant distributed computing capabilities to JAVA. Like CORBA, RMI over IIOP uses IIOP as its communication protocol. IIOP eases legacy application and platform integration by allowing application components written in C++, SmallTalk, and other CORBA supported languages to communicate with components running on the JAVA platform. For “manage anywhere” purposes and web technology integration, the various NMS programs may also run within a web browser. In addition, the NMS programs may integrate with Hewlett Packard’s (HP’s) Network Node Manager (NNM™) to provide the convenience of a network map, event aggregation/filtering, and integration with other vendor’s networking. From HP NNM a context-sensitive launch into an NMS server may be executed.

The NMS server also keeps track of important statistics including average client/server response times and response times to each network device. By looking at these statistics over time, it is possible for network administrators to determine when it is time to grow the management system by adding another server. In addition, each NMS server gathers the name, IP address and status of other NMS servers in the telecommunication network,

determines the number of NMS clients and network devices to which it is connected, tracks its own operation time, the number of transactions it has handled since initialization, determines the “top talkers” (i.e., network devices associated with high numbers of transactions with the server), and the number of communications errors it has experienced. These statistics help the network administrator tune the NMS to provide better overall management service.

NMS database 61 may be remote or local with respect to the network device(s) that it is managing. For example, the NMS database may be maintained on a computer system outside the domain of the network device (i.e., remote) and communications between the network device and the computer system may occur over a wide area network (WAN) or the Internet. Preferably, the NMS database is maintained on a computer system within the same domain as the network device (i.e., local) and communications between the network device and the computer system may occur over a local area network (LAN). This reduces network management traffic over a WAN or the Internet.

Many telecommunications networks include domains in various geographical locations, and network managers often need to see data combined from these different domains to determine how the overall network is performing. To assist with the management of wide spread networks and still minimize the network management traffic sent over WANs and the Internet, each domain may include an NMS database 61 and particular / selected data from each NMS database may be replicated (or “rolled up”) to remote NMS databases 854a-854n that are in particular centralized locations. Referring to Fig. 2b, for example, a telecommunications network may include at least three LAN domains 855a-855c where each domain includes multiple network devices 540 and an NMS database 61. Domain 855a may be located in the Boston, Massachusetts area, domain 855b may be located in the Chicago, Illinois area and domain 855c may be located in the San Francisco, California area. NMS servers 851a-851f may be located within each domain or in a separate domain. Similarly, one or more NMS clients may be coupled to each NMS server and located in the same domain as the NMS server or in different domains. In addition, one NMS client may be coupled with multiple NMS servers. For example,

NMS servers 851a-851c and NMS clients 850a-850k may be located in domain 856a (e.g., Dallas, Texas) while NMS servers 851d-851f and NMS clients 850m-850u may be located in domain 856b (e.g., New York, New York). Each NMS server may be used to manage each domain 855a-855c or, preferably, one NMS server in each server domain 856a-856b is used to manage all of the network devices within one network device domain 855a-855c. A single domain may include network devices and NMS clients and servers.

Network administrators use the NMS clients to configure network devices in each of the domains through the NMS servers. The network devices replicate changes made to their internal configuration databases (42, Fig. 2a) to a local NMS database 61. In addition, the data collector server copies all logging data into NMS database 61 or a separate logging database (not shown). Each local NMS database may also replicate selected data to central NMS database(s) 854a-854n in accordance with instructions from the network administrator. Other programs may then access the central database to retrieve and combine data from multiple network devices in multiple domains and then present this data to the network administrator. Importantly, network management traffic over WANs and the Internet are minimized since all data is not copied to the central NMS database. For example, local logging data may only be stored in the local NMS databases 61 (or local logging database) and not replicated to one of the central NMS database.

#### Logical System Model:

As previously mentioned, to avoid having to manually synchronize all integration interfaces between the various programs, the APIs for both NMS and network device programs are generated using a code generation system from the same logical system model. In addition, the APIs for the data repository software used by the programs are also generated from the same logical system model to ensure that the programs use the data in the same way. Each model within the logical system model contains metadata defining an object / entity, attributes for the object and the object's relationships with other objects. Upgrading / modifying an object is, therefore, much simpler than in current systems, since the relationship between objects, including both hardware and

software, and attributes required for each object are clearly defined in one location. When changes are made, the logical system model clearly shows what other programs are affected and, therefore, may also need to be changed. Modeling the hardware and software provides a clean separation of function and form and enables sophisticated dynamic software modularity.

A code generation system uses the attributes and metadata within each model to generate the APIs for each program and ensure lockstep synchronization. The logical model and code generation system may also be used to create test code to test the network device programs and NMS programs. Use of the logical model and code generation system saves development, test and integration time and ensures that all relationships between programs are in lockstep synchronization. In addition, use of the logical model and code generation system facilitates hardware portability, seamless extensibility and unprecedented availability and modularity.

Referring to Fig. 3a, a logical system model 280 is created using the object modeling notation and a model generation tool, for example, Rational Rose 2000 Modeler Edition available from Rational Software Corporation in Lexington, Massachusetts. A managed device 282 represents the top level system connected to models representing both hardware 284 and data objects used by software applications 286. Hardware model 284 includes models representing specific pieces of hardware, for example, chassis 288, shelf 290, slot 292 and printed circuit board 294. The logical model is capable of showing containment, that is, typically, there are many shelves per chassis (1:N), many slots per shelf (1:N) and one board per slot (1:1). Shelf 290 is a parent class generalizing multiple shelf models, including various functional shelves 296a-296n as well as one or more system shelves, for example, for fans 298 and power 300. Board 294 is also a parent class having multiple board models, including various functional boards without external physical ports 302a-302n (e.g., central processor 12, Fig. 1; 542-543, Fig. 35; and switch fabric cards, Fig. 35) and various functional boards 304a-304n (e.g., cross connection cards 562a-562b and forwarding cards 546a-546e, Fig. 35) that connect to boards 306 with external physical ports (e.g., universal port cards 554a-554h, Fig. 35). Hardware

model 284 also includes an external physical port model 308. Port model 308 is coupled to one or more specific port models, for example, synchronous optical network (SONET) protocol port 310, and a physical service endpoint model 312.

Hardware model 284 includes models for all hardware that may be available on computer system 10 (Fig. 1) / network device 540 (Fig. 35) whether a particular computer system / network device uses all the available hardware or not. The model defines the metadata for the system whereas the presence of hardware in an actual network device is represented in instance data. All shelves and slots may not be populated. In addition, there may be multiple classes. It should be understood that SONET port 310 is an example of one type of port that may be supported by computer system 10. A model is created for each type of port available on computer system 10, including, for example, Ethernet, Dense Wavelength Division Multiplexing (DWDM) or Digital Signal, Level 3 (DS3). The NMS (described below) uses the hardware model and instance data to display a graphical picture of computer system 10 / network device 540 to a user.

Service endpoint model 314 spans the software and hardware models within logical model 280. It is a parent class including a physical service endpoint model 312 and a logical service endpoint model 316. Since the links between the software model and hardware model are minimal, either may be changed (e.g., upgraded or modified) and easily integrated with the other. In addition, multiple models (e.g., 280) may be created for many different types of managed devices (e.g., 282). The software model may be the same or similar for each different type of managed device even if the hardware – and hardware models – corresponding to the different managed devices are very different. Similarly, the hardware model may be the same or similar for different managed devices but the software models may be different for each. The different software models may reflect different customer needs.

Software model 286 includes models of data objects used by each of the software processes (e.g., applications, device drivers, system services) available on computer system 10 / network device 540. All applications and device drivers may not be used in

each computer system / network device. As one example, ATM model 318 is shown. It should be understood that software model 286 may also include models for other applications, for example, Internet Protocol (IP) applications, Frame Relay and Multi-Protocol Label Switching (MPLS) applications. Models of other processes (e.g., device drivers and system services) are not shown for convenience.

For each process, models of configurable objects managed by those processes are also created. For example, models of ATM configurable objects are coupled to ATM model 318, including models for a soft permanent virtual path (SPVP) 320, a soft permanent virtual circuit (SPVC) 321, a switch address 322, a cross-connection 323, a permanent virtual path (PVP) cross-connection 324, a permanent virtual circuit (PVC) cross-connection 325, a virtual ATM interface 326, a virtual path link 327, a virtual circuit link 328, logging 329, an ILMI reference 330, PNNI 331, a traffic descriptor 332, an ATM interface 333 and logical service endpoint 316. As described above, logical service endpoint model 316 is coupled to service endpoint model 314. It is also coupled to ATM interface model 333.

The logical model is layered on the physical computer system to add a layer of abstraction between the physical system and the software applications. Adding or removing known (i.e., not new) hardware from the computer system will not require changes to the logical model or the software applications. However, changes to the physical system, for example, adding a new type of board, will require changes to the logical model. In addition, the logical model is modified when new or upgraded processes are created. Changes to an object model within the logical model may require changes to other object models within the logical model. It is possible for the logical model to simultaneously support multiple versions of the same software processes (e.g., upgraded and older). In essence, the logical model insulates software applications from changes to the hardware models and vice-versa.

To further decouple software processes from the logical model – as well as the physical system – another layer of abstraction is added in the form of version-stamped views. A

view is a logical slice of the logical model and defines a particular set of data within the logical model to which an associated process has access. Version stamped views allow multiple versions of the same process to be supported by the same logical model since each version-stamped view limits the data that a corresponding process “views” or has access to, to the data relevant to the version of that process. Similarly, views allow multiple different processes to use the same logical model.

#### Code Generation System:

Referring to Fig. 3b, logical model 280 is used as input to a code generation system 336. The code generation system creates a view identification (id) and an application programming interface (API) 338 for each process that requires configuration data. For example, a view id and an API may be created for each ATM application 339a-339n, each SONET application 340a-340n, each MPLS application 342a-342n and each IP application 341a-341n. In addition, a view id and API is also created for each device driver process, for example, device drivers 343a-343n, and for modular system services (MSS) 345a-345n (described below), for example, a Master Control Driver (MCD), a System Resiliency Manager (SRM), and a Software Management System (SMS). The code generation system provides data consistency across processes, centralized tuning and an abstraction of embedded configuration and NMS databases (described below) ensuring that changes to their database schema (i.e., configuration tables and relationships) do not affect existing processes.

The code generation system also creates a data definition language (DDL) file 344 including structured query language (SQL) commands used to construct the database schema, that is, the various tables and views within a configuration database 346, and a DDL file 348 including SQL commands used to construct various tables and SQL views within a network management (NMS) database 350 (described below). This is also referred to as converting the logical model into a database schema and various SQL views look at particular portions of that schema within the database. If the same database software is used for both the configuration and NMS databases, then one DDL file may be used for both.

The databases do not have to be generated from a logical model for views to work. Instead, database files can be supplied directly without having to generate them using the code generation system. Similarly, instead of using a logical model as an input to the code generation system, a MIB “model” may be used. For example, relationships between various MIBs and MIB objects may be written (i.e., coded) and then this “model” may be used as input to the code generation system.

Referring to Fig. 3c, applications 352a-352n (e.g., SONET driver 863, SONET application 860, MSS 866, etc.) each have an associated view 354a-354n of configuration database 42. The views may be similar allowing each application to view similar data within configuration database 42. For example, each application may be ATM version 1.0 and each view may be ATM view version 1.3. Instead, the applications and views may be different versions. For example, application 352a may be ATM version 1.0 and view 354a may be ATM view version 1.3 while application 352b is ATM version 1.7 and view 354b is ATM view version 1.5. A later version, for example, ATM version 1.7, of the same application may represent an upgrade of that application and its corresponding view allows the upgraded application access only to data relevant to the upgraded version and not data relevant to the older version. If the upgraded version of the application uses the same configuration data as an older version, then the view version may be the same for both applications. In addition, application 352n may represent a completely different type of application, for example, MPLS, and view 354n allows it to have access to data relevant to MPLS and not ATM or any other application. Consequently, through the use of database views, different versions of the same software applications and different types of software applications may be executed on computer system 10 simultaneously.

Views also allow the logical model and physical system to be changed, evolved and grown to support new applications and hardware without having to change existing applications. In addition, software applications may be upgraded and downgraded independent of each other and without having to re-boot computer system 10 / network device 540. For example, after computer system 10 is shipped to a customer, changes



may be made to hardware or software. For instance, a new version of an application, for example, ATM version 2.0, may be created or new hardware may be released requiring a new or upgraded device driver process. To make this a new process and/or hardware available to the user of computer system 10, first the software image including the new process must be re-built.

Referring again to Fig. 3b, logical model 280 may be changed (280') to include models representing the new software and/or hardware. Code generation system 336 then uses new logical model 280' to re-generate view ids and APIs 338' for each application, including, for example, ATM version two 360 and device driver 362, and DDL files 344' and 348'. The new application(s) and/or device driver(s) processes then bind to the new view ids and APIs. A copy of the new application(s) and/or device driver process as well as the new DDL files and any new hardware are sent to the user of computer system 10. The user can then download the new software and plug the new hardware into computer system 10. The upgrade process is described in more detail below. Similarly, if models are upgraded / modified to reflect upgrades / modifications to software or hardware, then the new logical model is provided to the code generation system which re-generates view ids and APIs for each process / program / application. Again, the new applications are linked with the new view ids and APIs and the new applications and/or hardware are provided to the user.

Again referring to Fig. 3b, the code generation system also creates NMS JAVA interfaces 347 and persistent layer metadata 349. The JAVA interfaces are JAVA class files including get and put methods corresponding to attributes within the logical model, and as described below, the NMS servers use the NMS JAVA interfaces to construct models of each particular network device to which they are connected. Also described below, the NMS servers use the persistent layer metadata as well as run time configuration data to generate SQL configuration commands for use by the configuration database.

Prior to shipping computer system 10 to customers, a software build process is initiated to establish the software architecture and processes. The code generation system is the

first part of this process. Following the execution of the code generation system, each process when pulled into the build process links the associated view id and API into its image. For example, referring to Fig. 3d, to build a SONET application, source files, for example, a main application file 859a, a performance monitoring file 859b and an alarm monitoring file 859c, written in, for example, the C programming language (.c) are compiled into object code files (.o) 859a', 859b' and 859c'. Alternatively, the source files may be written in other programming languages, for example, JAVA (.java) or C++ (.cpp). The object files are then linked along with view ids and APIs from the code generation system corresponding to the SONET application, for example, SONET API 340a. The SONET API may be a library (.a) of many object files. Linking these files generates the SONET Application executable file (.exe) 860.

Referring to Fig. 3e, each of the executable files for use by the network device / computer system are then provided to a kit builder 861. For example, several SONET executable files (e.g., 860, 863), ATM executable files (e.g., 864a-864n), MPLS executable files (e.g., 865a-865n), MSS executable files 866a-866n and a DDL configuration database executable file 867 may be provided to kit builder 861. Alternatively, the DDL configuration database executable file may be executed and some data placed in the database prior to supplying the DDL file to the kit builder. The kit builder creates a computer system / network device installation kit 862 that is shipped to the customer with the computer system / network device or, later, alone after modifications and upgrades are made.

Referring to Fig. 3f, similarly, each of the executable files for the NMS is provided separately to the kit builder. For example, a DDL NMS database executable file 868, an NMS JAVA interfaces executable file 869, a persistent layer metadata executable file 870, an NMS server 885 and an NMS client 886 may be provided to kit builder 861. The kit builder creates an NMS installation kit 871 that is shipped to the customer for installation on a separate computer 62 (Fig. 9a). In addition, new versions of the NMS installation kit may be sent to customers later after upgrades / modifications are made. When installing the NMS, the customer / network administrator may choose to distribute

the various NMS processes as described above. Alternatively, one or more of the NMS programs, for example, the NMS JAVA interfaces and Persistent layer metadata executable files may be part of the network device installation kit and later passed from the network device to the NMS server, or part of both the network device installation kit and the NMS installation kit.

When the computer system is powered-up for the first time, as described below, configuration database software uses DDL file 867 to create a configuration database 42 with the necessary configuration tables and active queries. The NMS database software uses DDL file 868 to create NMS database 61 with corresponding configuration tables. Memory and storage space within network devices is typically very limited. The configuration database software is robust and takes a considerable amount of these limited resources but provides many advantages as described below.

As described above, logical model 280 (Fig. 3b) may be provided as an input to code generation system 336 in order to generate database views and APIs for NMS programs and network device programs to synchronize the integration interfaces between those programs. Where a telecommunications network includes multiple similar network devices, the same installation kit may be used to install software on each network device to provide synchronization across the network. Typically, however, networks include multiple different network devices as well as multiple similar network devices. A logical model may be created for each different type of network device and a different installation kit may be implemented on each different type of network device.

Instead, of providing a logical model (e.g., 280, Fig. 3b) that represents a single network device, a logical model may be provided that represents multiple different managed devices – that is, multiple network devices and the relationship between the network devices. Alternatively, multiple logical models 280 and 887a-887n – representing multiple network devices -- may be provided, including relationships with other logical models. In either case, providing multiple logical models or one logical model representing multiple network devices and their relationships as an input(s) to the code

generation system allows for synchronization of NMS programs and network device programs (e.g., 901a-901n) across an entire network. The code generation system in combination with one or more logical models provides a powerful tool for synchronizing distributed telecommunication network applications.

The logical model or models may also be used for simulation of a network device and/or a network of many network devices, which may be useful for scalability testing.

In addition to providing view ids and APIs, the code generation system may also provide code used to push data directly into a third party code API. For example, where an API of a third party program expects particular data, the code generation system may provide this data by retrieving the data from the central repository and calling the third-party programs API. In this situation, the code generation system is performing as a “data pump”.

#### Configuration:

Once the network device programs have been installed on network device 540 (Fig. 35), and the NMS programs have been installed on one or more computers (e.g., 62), the network administrator may configure the network device / provision services within the network device. Hereinafter, the term “configure” includes “provisioning services”. Referring to Fig. 4a, the NMS client displays a graphical user interface (GUI) 895 to the administrator including a navigation tree / menu 898. Selecting a branch of the navigation tree causes the NMS client to display information corresponding to that branch. For example, selecting Devices branch 898a within the tree causes the NMS client to display a list 898b of IP addresses and/or domain name server (DNS) names corresponding to network devices that may be managed by the administrator. The list corresponds to a profile associated with the administrator’s user name and password. Profiles are described in detail below.

If the administrator's profile includes the appropriate authority, then the administrator may add new devices to list 898b. To add a new device, the administrator selects Devices branch 898a and clicks the right mouse button to cause a pop-up menu 898c (Fig. 4b) to appear. The administrator then selects the Add Devices option to cause a dialog box 898d (Fig. 4c) to appear. The administrator may then type in an IP address (e.g., 192.168.9.203) or a DNS name into field 898e and select an Add button 898f to add the device to Device list window 898g (Fig. 4d). The administrator may then add one or more other devices in a similar manner. The administrator may also delete a device from the Device list window by selecting the device and then selecting a Delete button 898h, or the administrator may cancel out of the dialog box without adding any new devices by selecting Cancel button 898i. When finished, the administrator may select an OK button 898j to add any new devices in Device list 898g to navigation tree 898a (Fig. 4e).

To configure a network device, the administrator begins by selecting (step 874, Fig. 3g) a particular network device to configure, for example, the network device corresponding to IP address 192.168.9.202 (Fig. 4f). The NMS client then informs (step 875, Fig. 3g) an NMS server of the particular network device to be configured. Since many NMS clients may connect to the same NMS server, the NMS server first checks its local cache to determine if it is already managing the network device for another NMS client. If so, the NMS server sends data from the cache to the NMS client. If not, the NMS server using JDBC connects to the network device and reads the data / object structure for the physical aspects of the device from the configuration database within the network device into its local cache and uses that information with the JAVA interfaces to construct (step 876) a model of the network device. The server provides (step 877) this information to the client, which displays (step 878) a graphical representation 896a (Fig. 4f) of the network device to the administrator indicating the hardware and services available in the selected network device and the current configuration and currently provisioned services. Configuration changes received by an NMS server – from either an NMS client or directly from the network device's configuration database when changes are made through the network device's CLI interface -- are sent by the NMS server to any other NMS clients connected to that server and managing the same network device. This

provides scalability, since the device is not burdened with multiple clients subscribing for traps, and ensures each NMS client provides an accurate view of the network device.

Referring to Figs. 4f-4l, graphical representation 896a (i.e., device view, device mimic) in graphic window 896b may include many views of the network device. For example, device mimic 896a is shown in Fig. 4f displaying a front view of the components in the upper portion of network device 540 (Fig. 35). The administrator may use scroll bar 926a to scroll down and view lower portions of the front of the network device as shown in Fig. 4g. The administrator may also use image scale button 926b to change the size of graphic 896a. For example, the administrator may shrink the network device image to allow more of the device image to be visible in graphic window 896b, as shown in Fig. 4h. This view corresponds to the block diagram of network device 540 shown in Fig. 41a. For instance, upper fan tray 634 and middle fan trays 630 and 632 are shown. In addition, forwarding cards (e.g., 546a and 548e), cross-connection cards (e.g., 562a, 562b, 564b, 566a, 568b), and external processor control cards (e.g., 542b and 543b) are shown.

GUI 895 also includes several splitter bars 895a-895c (Fig. 4f) to allow the administrator to change the size of the various panels (e.g., 896b, 897 and 898). In addition, GUI 895 includes a status bar 895d. The status bar may include various fields such as a server field 895e, a Mode field 895f, a Profile field 895g and an active field 895h. The server field may provide the IP address or DNS name of the NMS server, and the profile field may provide the username that the administrator logged in under. The active field will provide updated status, for example, ready, or ask the administrator to take particular steps. The mode field will indicate an on-line mode (i.e., typical operation) or an off-line mode (described in detail below).

Device mimic 896a may also provide one or more visual indications as to whether a card is present in each slot or whether a slot is empty. For example, in one embodiment, the forwarding cards (e.g., 546a and 548e) in the upper portion of the network device are displayed in a dark color to indicate the cards are present while the lower slots (e.g., 928a

and 929e) are shown in a lighter color to indicate that the slots are empty. Other visual indications may also be used. For example, a graphical representation of the actual card faceplate may be added to device mimic 896a when a card is present and a blank faceplate may be added when the slot is empty. Moreover, this may be done for any of the cards that may or may not be present in a working network device. For example, the upper cross-connection cards may be displayed in a dark color to indicate they are present while the lower cross-connection card slots may be displayed in a lighter color to indicate the slots are empty.

In addition, a back view and other views of the network device may also be shown. For example, the administrator may use a mouse to move a cursor into an empty portion of graphic window 896b and click the right mouse button to cause a pop-up menu to appear listing the various views available for the network device. In one embodiment, the only other view is a back view and pop-up menu 927 is displayed. Alternatively, short cuts may be set up. For example, double clicking the left mouse button may automatically cause graphic 896a to display the back view of the network device, and another double click may cause graphic 896a to again display the front view. As another alternative, a pull down menu may be provided to allow an administrator to select between various views.

Device mimic 896a is shown in Fig. 4i displaying a back view of the components in the upper portion of network device 540 (Fig. 35). Again the administrator may use scroll bar 926a and/or image scale button 926b to view lower portions (Figs. 4j and 4k) of the back of the network device or more of the network device by shrinking the graphic (Fig. 4l). These views correspond to the block diagram of network device 540 shown in Fig. 41b. For example, upper fan tray 628 (Fig. 4i), management interface (MI) card 621 (Fig. 4i) and lower fan tray 626 (Fig. 4k) are shown. In addition, universal port cards (e.g., 556h, 554a and 560h, Fig. 4l), switch fabric cards (e.g., 570a and 570b) and internal processor control cards (e.g., 542a and 543a) are also shown. Again, graphic 896a may use a visual indicator to clearly show whether a card is present in a slot or whether the slot is empty. In this example, the visual indicator for universal port cards is the display

of the ports available on each card. For example, universal port card 554a is present as indicated by the graphical representation of ports (e.g., 930, Fig. 4l) available on that card, while universal port card 558a (Fig. 41b) is not present as indicated by a blank slot 931.

Since the GUI has limited screen real estate and the network device may be large and loaded with many different types of components (e.g., modules, ports, fan trays, power connections), in addition to the device mimic views described above, GUI 895 may also provide a system view menu option 954 (Fig. 4m). If an administrator selects this option, a separate pull away window 955 (Fig. 4n) is displayed for the administrator including both a front view 955a and a back view 955b of the network device corresponding to the front and back views displayed by the device mimic. The administrator may keep this separate pull away window up and visible while provisioning services through the GUI. Moreover, the GUI remains linked with the pull away window such that if the administrator selects a component in the pull away window, the device mimic displays that portion of the device and highlights that component. Similarly, if the administrator selects a component within the device mimic, the pull away window also highlights the selected component. Thus, the pull away window may further help the administrator navigate in the device mimic.

Device mimic 896a may also indicate the status of components. For example, ports and/or cards may be green for normal operation, red if there are errors and yellow if there are warnings. In one embodiment, a port may be colored, for example, light green or gray if it is available but not yet configured and colored dark green after being configured. Other colors or graphical textures may also be used show visible status. To further ease a network administrator's tasks, the GUI may present pop-up windows or tool tips containing information about each card and/or port when the administrator moves the cursor over the card or port. For example, when the administrator moves the cursor over universal port card 556f (Fig. 4o), pop-up window 932a may be displayed to tell the administrator that the card is a 16 Port OC3 Universal Port Module in Shelf 11 / Slot 3. Similarly, if the administrator moves the cursor over universal port card 556e



(Fig. 4p), pop-up window 932b appears indicating that the card is a 16 Port OC12 Universal Port Module in Shelf 11 / Slot 4, and if the cursor is moved over universal port cards 556d (Fig. 4q) or 556c (Fig. 4r), then pop-up windows 932c and 932d appear indicating the cards are 4 Port OC48 Universal Port Module in Shelf 11 / Slot 5 and 8 Port OC12 Universal Port Module in Shelf 11 / Slot 6, respectively. If the administrator moves the cursor over a port, for example, port 933 (Fig. 4s), then pop-up window 932e appears indicating the port is an OC12 in Shelf 11 / Slot 4 / Port 1.

The views are used to provide management context. The GUI may also include a configuration / service status window 897 for displaying current configuration and service provisioning details. Again, these details are provided to the NMS client by the NMS server, which reads the data from the network device's configuration database. The status window may include many tabs / folders for displaying various data about the network device configuration. In one embodiment, the status window includes a System tab 934 (Fig. 4s), which is displayed when the server first accesses the network device. This tab provides system level data such as the system name 934a, System Description 934b, System Contact 934c, System Location 934d, System IP Address 934e (or DNS name), System Up Time 934f, System identification (ID) 934g and System Services 934h. Modifications to data displayed in 934a-934e may be made by the administrator and committed by selecting the Apply button 935. The NMS client then passes this information to the NMS server, which then writes a copy of the data in the network device's configuration database and broadcasts the changes to any other NMS clients managing the same network device. The administrator may also reset the network device by selecting the Reset System button 935b and then refresh the System tab data by selecting the Refresh button 935c.

The status window may also include a Modules tab 936 (Fig. 4t), which includes an inventory of the available modules in the network device and various details about those modules such as where they are located (e.g., shelf and slot, back or front). The inventory may also include a description of the type of module, version number, manufacturing date, part number, etc. In addition, the inventory may include run time

data such as the operational status and temperature. The NMS server may continuously supply the NMS client(s) with the run time data by reading the network device configuration database or NMS database. Device mimic 896a is linked with status window 897, such that selecting a module in device mimic 896a causes the Module tab to highlight a line in the inventory corresponding to that card. For example, if an administrator selects universal port card 556d, device mimic 896a highlights that module and the Module tab highlights a line 937 in the inventory corresponding to the card in Shelf 11 / Slot 5. Similarly, if the administrator selects a line in the Module tab inventory, device mimic 896a highlights the corresponding module. Double clicking the left mouse button on a selected module may cause a dialog box to appear and the administrator may modify particular parameters such as an enable/disable parameter.

The status window may also include a Ports tab 938 (Fig. 4u), which displays an inventory of the available ports in the network device and various details about each port such as where they are located (shelf, slot and port; back or front). The inventory may also include a description of the port name, type and speed as well as run time data such as administrative status, operational status and link status. Again, device mimic 896a is linked with status window 897 such that selecting a port within device mimic 896a causes the Port tab to highlight a line in the inventory corresponding to that port. For example, if the administrator selects port 939a (port 1, slot 4) on card 556e, then the Port tab highlights a line 939b within the inventory corresponding to that port. Similarly, if the administrator selects a line from the inventory in the Port tab, device mimic 896a highlights the corresponding port. Again double clicking the left mouse button on a selected port may cause a dialog box to appear and the administrator may modify particular parameters such as an enable/disable parameter.

Another tab in the status window may be a SONET Interface tab 940 (Fig. 4v), which includes an inventory of SONET ports in the network device and various details about each port such as where they are located (shelf and slot; back or front). Medium type (e.g., SONET, Synchronous Digital Hierarchy (SDH)) may also be displayed as well as circuit ID, Line Type, Line Coding, Loopback, Laser Status, Path Count and other

details. Again, device mimic 896a is lined with status window 897 such that selecting a port within device mimic 896a causes the SONET Interface tab to highlight a line in the inventory corresponding to that SONET port. For example, if the administrator selects port 941a (port 2, slot 5) on card 556d, then the SONET Interface tab highlights line 941b corresponding to that port. Similarly, if the administrator selects a line from the inventory in the SONET Interface tab, device mimic 896a highlights the corresponding port. Again, double clicking the left mouse button on a selected SONET interface may cause a dialog box to appear and the administrator may modify particular parameters such as an enable/disable parameter.

The System tab data as well as the Modules tab, Ports tab and SONET Interface tab data all represent physical aspects of the network device. The remaining tabs, including SONET Paths tab 942 (Fig. 4w), ATM Interfaces tab 946, Virtual ATM Interfaces tab 947 and Virtual Connections tab 948, display configuration details and, thus, display no data until the device is configured. In addition, these configuration tabs 942, 946-948 are dialog chained together with wizard-like properties to guide an administrator through configuration details. Through these tabs within the GUI (i.e., graphical context), therefore, the administrator then makes (step 879, Fig. 3g) configuration selections. For example, to configure a SONET path, the administrator may begin by selecting a port (e.g., 939a on card 556e, Fig. 5a) within device mimic 896a and clicking the right mouse button (i.e., context sensitive) to cause a pop-up menu 943 to be displayed listing available port configuration options. The administrator may then select the “Configure SONET Paths” option, which causes the GUI to display a SONET Path configuration wizard 944 (Fig. 5b).

The SONET Path configuration wizard guides the administrator through the task of setting up a SONET Path by presenting the administrator with valid configuration options and inserting default parameter values. As a result, the process of configuring SONET paths is simplified, and required administrator expertise is reduced since the administrator does not need to know or remember to provide each parameter value. In addition, the SONET Path wizard allows the administrator to configure multiple SONET Paths

simultaneously, thereby eliminating the repetition of similar configuration process steps required by current network management systems and reducing the time required to configure many SONET Paths. Moreover, the wizard validates configuration requests from the administrator to minimize the potential for mis-configuration.

In one embodiment, the SONET Path wizard displays SONET line data 944a (e.g., slot 4, port 1, OC12) and three configuration choices 944b, 944c and 944d. The first two configuration choices provide “short cuts” to typical configurations. If the administrator selects the first configuration option 944b (Fig. 5c), the SONET Path wizard creates a single concatenated path. In the current example, the selected port is an OC12, and the single concatenated path is an STS-12c. The wizard assigns and graphically displays the position 944e and width 944f of the STS-12c path and also displays a SONET Path table 944g including an inventory having an entry for the SONET STS-12c path and each of the default parameters assigned to that SONET path. The position of each SONET path is chosen such that each path lines up on a valid boundary based on SONET protocol constraints.

If the administrator selects the second configuration option 944c (Figs. 5d and 5e), the SONET Path wizard creates one or more valid SONET paths that fully utilize the port capacity. In the current example, where the selected port is an OC12 port, in one embodiment, the second configuration option 944c allows the administrator to quickly create four STS-3c paths (Fig. 5d) or one concatenated STS-12c (Fig. 5e). The user may select the number of paths in window 944s or the type of path in window 944t. Windows 944s and 944t are linked and, thus, always present the user with consistent options. For example, if the administrator selects 4 paths in window 944s, window 944t displays STS-3c and if the administrator selects STS-12c in window 944t, window 944s displays 1 path. Again, the SONET path wizard graphically displays the position 944d and width 944f of the SONET paths created and also displays them in SONET Path table 944g along with the default parameters assigned to each SONET path.

The third configuration option allows the administrator to custom configure a port thereby providing the administrator with more flexibility. If the administrator selects the third configuration option 944d (Fig. 5f), the SONET Path wizard displays a function window 944h. The function window provides a list of available SONET Path types 944i and also displays an allocated SONET path window 944j. In this example, only the STS-3c path type is listed in the available SONET Path types window, and if the administrator wishes to configure a single STS-12c path, then they need to select the first or second configuration option 944b or 944c. To configure one or more SONET STS-3c paths, the administrator selects the STS-3c SONET path type and then selects ADD button 944k. The SONET Path wizard adds STS-3c path 944l to the allocated SONET paths window and then displays the position 944e and width 944f of the SONET path and updates Path table 944g with a listing of that SONET path including the assigned parameters. In this example, two STS-3c paths 944l and 944m are configured in this way on the selected port. The administrator may select an allocated path (e.g., 944m or 944n) in window 944j and then select the remove button 944n to delete a configured path, or the administrator may select the clear button 944o to delete each of the configured paths from window 944j. Moreover, the administrator may select an allocated path and use up arrow 944u and down arrow 944v to change the position 944e.

In any of the SONET Path windows (Figs. 5c-5f), the administrator may select a path in the SONET path table and double click on the left mouse button or select a modify button 944p to cause the GUI to display a dialog box through which the administrator may modify the default parameters assigned to each path. The wizard validates each parameter change and prevents invalid values from being entered. The administrator may also select a cancel button 944q to exit the SONET path wizard without accepting any of the configured or modified paths. If, instead, the administrator wants to exit the SONET Path wizard and accept the configured SONET Paths, the administrator selects an OK button 944r.

Once the administrator selects the OK button, the NMS client validates the parameters as far as possible within the client's view of the device and passes (step 880, Fig. 3g) this

run time / instance configuration data, including all configured SONET path parameters, to the NMS server. The NMS server validates (step 881) the data received based on its view of the world and if not correct, sends an error message to the NMS client, which notifies the administrator. Thus, the NMS server re-validates all data from the NMS clients to ensure that it is consistent with changes made by any other NMS client or by an administrator using the network device's CLI. After a successful NMS server validation, the Persistent layer software within the server uses this data to generate (step 882) SQL commands, which the server sends to the configuration database software executing on the network device. This is referred to as "persisting" the configuration change. Receipt of the SQL commands triggers a validation of the data within the network device as well. If the validation is not successful, then the network device sends an error message to the NMS server, and the NMS server sends an error message to the NMS client, which displays the error to the administrator. If the validation is successful, the configuration database software then executes (step 883) the SQL commands to fill in or change the appropriate configuration tables.

As just described, the configuration process provides a tiered approach to validation of configuration data. The NMS client validates configuration data received from an administrator according to its view of the network device. Since multiple clients may manage the same network device through the same NMS server, the NMS server re-validates received configuration data. Similarly, because the network device may be managed simultaneously by multiple NMS servers, the network device itself re-validates received configuration data. This tiered validation provides reliability and scalability to the NMS.

The configuration database software then sends (step 884) active query notices, described in more detail below, to appropriate applications executing within the network device to complete the administrator's configuration request (step 885). Active query notices may also be used to update the NMS database with the changes made to the configuration database. In addition, a Configuration Synchronization process running in the network device may also be notified through active queries when any configuration changes are

made or, perhaps, only when certain configuration changes are made. As previously mentioned, the network device may be connected to multiple NMS Servers. To maintain synchronization, the Configuration Synchronization program broadcasts configuration changes to each attached NMS server. This may be accomplished by issuing reliable (i.e., over TCP) SNMP configuration change traps to each NMS server. Configuration change traps received by the NMS servers are then multicast / broadcast to all attached NMS clients. Thus, all NMS servers, NMS clients, and databases (both internal and external to the network device) remain synchronized.

Even a simple configuration request from a network administrator may require several changes to one or more configuration database tables. Under certain circumstances, all the changes may not be able to be completed. For example, the connection between the computer system executing the NMS and the network device may go down or the NMS or the network device may crash in the middle of configuring the network device. Current network management systems make configuration changes in a central data repository and pass these changes to network devices using SNMP “sets”. Since changes made through SNMP are committed immediately (i.e., written to the data repository), an uncompleted configuration (series of related “sets”) will leave the network device in a partially configured state (e.g., “dangling” partial configuration records) that is different from the configuration state in the central data repository being used by the NMS. This may cause errors or a network device and/or network failure. To avoid this situation, the configuration database executes groups of SQL commands representing one configuration change as a relational database transaction, such that none of the changes are committed to the configuration database until all commands are successfully executed. The configuration database then notifies the server as to the success or failure of the configuration change and the server notifies the client. If the server receives a communication failure notification, then the server re-sends the SQL commands to re-start the configuration changes. Upon the receipt of any other type of failure, the client notifies the user.

If the administrator now selects the same port 939a (Fig. 5a), clicks the right mouse button and selects the Configure SONET Paths option in pop-up menu 943, the SONET path wizard may be displayed as shown in Fig. 5f, or alternatively, a SONET Path Configuration dialog box 945 (Fig. 5g) may be displayed. The SONET Path dialog box is similar to the SONET Path wizard except that it does not include the three configuration options 944b-944d. Similar to the SONET Path wizard, dialog box 945 displays SONET line data 945a (e.g., slot 4, port 1, OC12), SONET Path table 945g and SONET path position 945e and width 945f. The administrator may modify parameters of a configured SONET path by selecting the path in the Path table and double clicking the right mouse button or selecting a Modify button 945p. The administrator may also add a SONET path by selecting an Add button 945k, which causes the SONET path dialog box to display another SONET path in the path table. Again, the administrator may modify the parameters by selecting the new SONET path and then the Modify button. The administrator may also delete a SONET path by selecting it within the SONET Path table and then selecting a Delete button 945m. The administrator may cancel any changes made by selecting a Cancel button 945n, or the administrator may commit any changes made by selecting an OK button 945r.

The SONET path wizard provides the administrator with available and valid configuration options. The options are consistent with constraints imposed by the SONET protocol and the network device itself. The options may be further limited by other constraints, for example, customer subscription limitations. That is, ports or modules may be associated with particular customers and the SONET Path wizard may present the administrator with configuration options that match services to which the customer is entitled and no more. For example, a particular customer may have only purchased service on two STS-3c SONET paths on an OC12 SONET port, and the SONET Path wizard may prevent the administrator from configuring more than these two STS-3c SONET paths for that customer.

By providing default values for SONET Path parameters and providing only configuration options that meet various protocol, network device and other constraints,



the process of configuring SONET paths is made simpler and more efficient, the necessary expertise required to configure SONET paths is reduced and the potential for mis-configurations is reduced. In addition, as the administrator provides input to the SONET path configuration wizard, the wizard validates the input and presents the administrator with configuration options consistent with both the original constraints and the administrator's configuration choices. This further reduces the necessary expertise required to configure SONET paths and further minimizes the potential for mis-configurations. Moreover, short cuts presented to the administrator may increase the speed and efficiency of configuring SONET paths.

If the administrator now selects SONET path tab 942 (Fig. 5h), GUI 895 displays an inventory including the two STS-3c paths (942a and 942b) just configured. The SONET path tab includes information about each SONET path, such as SONET line information (e.g., shelf, slot and port), Path Position, Path Width, Ingress Connection and Egress Connection. It may also include Path Type and Service (e.g., Terminated ATM, Switched SONET), and a Path Name. The SONET Path configuration wizard may automatically assign the Path Name based on the shelf, slot and port. Parameters, such as Path Name, Path Width, Path Number and Path Type, may be changed by selecting a SONET path from the inventory and double clicking on that SONET path or selecting a Modify button (not shown) causing a dialog box to appear. The administrator may type in different parameter values or select from a pull-down list of available options within the dialog box.

Similarly, if the administrator selects an ATM Interfaces button 942c or directly selects the ATM Interfaces tab 946 (Fig 5i), GUI 895 displays an inventory including two ATM interfaces (946a and 946b) corresponding to the two STS-3c paths just configured. The SONET Path configuration wizard automatically assigns an ATM interface name based again on the shelf, slot and port. The SONET Path wizard also automatically assigns a minimum VPI bits and maximum VPI bits and a minimum and maximum VCI bits. Again, the ATM Interfaces tab lists information such as the shelf, port and slot as well as the Path name and location of the card. The ATM Interfaces tab also lists the Virtual



Now when the administrator selects SONET Paths tab 942 (Fig. 5q), the inventory of paths includes the four new paths (942c-942f). Similarly, when the administrator selects ATM Interfaces tab 946 (Fig. 5r), the inventory of ATM interfaces includes four new interfaces (946c-946f) corresponding to the newly created SONET paths.

Instead of selecting a port in device mimic 896a and then the Configure SONET Paths option from a pop-up menu and instead of selecting a SONET interface in the SONET Interfaces tab and then selecting the Paths button, the SONET Path wizard may be accessed by the administrator from any view in the GUI by simply selecting a Wizard menu button 951 and then selecting a SONET Path option 951a (Fig. 5q) from a pull-down menu 951b. When the SONET path wizard appears, the SONET line data (i.e., slot, port and type) will be blank, and the administrator simply needs to provide this information to allow the SONET path wizard to select the appropriate port. If the administrator selects a port in the Ports tab prior to selecting the SONET path option from the wizard pull-down menu, then the SONET wizard will appear with this information displayed as the SONET line data but the administrator may modify this data to select a different port from the SONET wizard.

To create virtual connections between various ATM Interfaces / SONET Paths within the network device, the administrator first needs to create one or more virtual ATM interfaces for each ATM interface. At least two virtual ATM interfaces are required since two discrete virtual ATM interfaces are required for each virtual connection. In the case of a multipoint connection there will be one root ATM interface and many leafs. To do this, the administrator may select an ATM interface (e.g., 946b) from the inventory in the ATM Interfaces tab and then select a Virtual Interfaces button 946g to cause Virtual Interfaces tab 947 (Fig. 5s) to appear and display an inventory of all virtual interfaces associated with the selected ATM interface. In this example, no virtual ATM interfaces have yet been created, thus, none are displayed.

The Virtual ATM Interfaces tab also includes a device navigation tree 947a. The navigation tree is linked with the Virtual Interfaces button 946g (Fig. 5r) such that the device tree highlights the ATM interface (e.g., ATM-Path2\_11/4, Fig. 5s) that was selected when the Virtual Interfaces button was selected. When the Virtual Interfaces button is selected, the NMS client automatically requests virtual interface data corresponding to the selected ATM interface from the NMS server and then the NMS client displays this data in the Virtual ATM Interfaces tab. This saves memory space within the NMS client since only a small amount of data relevant to the virtual ATM interfaces associated with the selected ATM interface must be stored. In addition, since the amount of data is small, the data transfer is quick and reduces network traffic.

Instead the administrator may directly select Virtual ATM Interfaces tab 947 and then use the device tree 947a to locate the ATM interface they wish to configure with one or more virtual ATM interfaces. In this instance, the NMS client may again automatically request virtual interface data from the NMS server, or instead, the NMS client may simply use data stored in cache.

To return to the ATM Interfaces tab, the administrator may select a Back button 947d or directly select the ATM Interfaces tab. Once the appropriate ATM interface has been selected (e.g., ATM-Path2\_11/4/1) in the Virtual ATM Interfaces tab device tree 947a, then the administrator may select an ADD button 947b to cause a virtual ATM (V-ATM) Interfaces dialog box 950 (Fig. 5t) to appear.

GUI 895 automatically fills in dialog box 950 with default values for Connection type 950a, Version 950b and Administration Status 950c. The administrator may provide a Name or Alias 950d and may modify the other three parameters by selecting from the options provided in pull down menus. This and other dialog boxes may also have wizard-like properties. For example, only valid connection types, versions and administrative status choices are made available in corresponding pull-down menus. For instance, Version may be UNI Network 3.1, UNI Network 4.0, IISP User 3.0, IISP User 3.1, PNNI, IISP Network 3.0 or IISP Network 3.1, and Administration Status may be Up



configuration requests from the administrator to minimize the potential for mis-configuration.

The Virtual Connection configuration wizard includes a Connection Topology panel 952a and a Connection Type panel 952b. Within the Connection Topology panel the administrator is asked whether they want a point-to-point or point-to-multipoint connection, and within the Connection Type panel, the administrator is asked whether they want a Virtual Path Connection (VPC) or a Virtual Channel Connection (VCC). In addition, the administrator may indicate that they want the VPC or VCC made soft (SPVPC/SPVCC). Where the administrator chooses a point-to-point, VPC connection, the Virtual Connection wizard presents dialog box 953 (Fig. 5x).

The source (e.g., test1 in End Point 1 window 953a) for the point-to-point connection is automatically set to the virtual ATM interface (e.g., 947c, Fig. 5v) selected in Virtual ATM Interface tab 947 when the virtual connection button 947d was selected. The administrator may change the source simply by selecting another virtual ATM interface in device tree 953b, for example, test2. Similarly, the administrator selects a destination (e.g., test3 in End Point 2 window 953c) for the point-to-point connection by selecting a virtual ATM interface in device tree 953d, for example, test3. If the administrator had selected point-to-multipoint in Connection Topology panel 952a (Fig. 5w), then the user would select multiple destination devices from device tree 953d or the wizard may present the administrator with multiple End Point 2 windows in which to select the multiple destination devices. In addition, if within Connection Topology panel 952b (Fig. 5w) the administrator had elected to make the VPC or VCC soft (SPVPC/SPVCC), then the user may select in End Point 2 window 953c (Fig. 5x) a virtual ATM interface in another network device.

The virtual Connection wizard also contains a Connections Parameters window 953e, an End Point 1 Parameters window 953f and an End Point 2 Parameters window 953g. Again for point-to-multipoint, there will be multiple End Point 2 Parameters windows. Within the Connections Parameters window, the administrator may provide a Connection







Importantly, other configuration wizards in addition to the SONET Path configuration wizard and Virtual Connection configuration wizard may also be used to simplify service provisioning.

#### Custom Navigator:

In typical network management systems, the graphical user interface (GUI) provides static choices and is not flexible. That is, the screen flow provided by the GUI is predetermined and the administrator must walk through a predetermined set of screens each time a service is to be provisioned. To provide flexibility and further simplify the steps required to provision services within a network device, GUI 895, described in detail above, may also include a custom navigator tool that facilitates “dynamic menus”. When the administrator selects the custom navigator menu button 958 (Fig. 4x), a pop-up menu 958a displays a list of available “screen marks”. The list of screen marks may include default screen marks (e.g., Virtual ATM IF 958b and Virtual Connection 958c) and/or administrator created screen marks (e.g., test 958d).

When the administrator selects a particular screen mark, the custom navigator shortcuts the configuration process by jumping forward past various configuration screens to a particular configuration screen corresponding to the screen mark. For example, if the administrator selects a Virtual ATM IF screen mark 958b, the custom navigator presents the Virtual ATM Interface tab (Fig. 5u). The administrator may then select an ATM interface from device tree 947a and select Add button 947b to add a virtual ATM interface. Similarly, the administrator may select a Virtual Connection screen mark 958c, and the custom navigator automatically presents Virtual Connection wizard 952 (Fig. 5w).

Moreover, the custom navigator allows the administrator to create unique screen marks. For example, the administrator may provision SONET paths and ATM interfaces as described above, then select an ATM interface (e.g., 946b, Fig. 5r) in ATM interfaces tab 946 and select Virtual Interfaces button 946g to display Virtual ATM Interfaces tab 947 (Fig. 5s), and as described above, the devices tree 947a will highlight the selected ATM

interface. If the administrator believes they may want to return to the Virtual Interfaces tab multiple times to provision multiple virtual ATM interfaces for the selected ATM interface or other ATM interfaces near the selected ATM interface in device tree 947a, then the administrator would select a screen mark button 959 to create a screen mark for this configuration position. A dialog box would appear in which the administrator enters the name of the new screen mark (e.g., test 958d, Fig. 4x) and this new screen mark name is added to the list of screen marks 958a. The custom navigator then takes a “snap shot” of the metadata necessary to recreate the screen and the current configuration position (i.e., highlight ATM-Path2\_11/4/1). If the administrator now selects this screen mark while another tab is displayed, the custom navigator uses the metadata associated with the screen mark to present the screen shot displayed in Fig. 5s to the administrator updated with any other configuration changes made subsequent to the creation of the screen mark.

As a result, the administrator is provided with configuration short cuts, both default short cuts and ones created by the administrator himself. Many other screen marks may be created through GUI 895, and in each case, the screen marks may simplify the configuration process and save the administrator configuration time.

### Custom Wizard:

To provide additional flexibility and efficiency, an administrator may use a custom wizard tool to create unique custom wizards to reflect common screen sequences used by the administrator. To create a custom wizard, the administrator begins by selecting a Custom Wizard menu button 960 (Fig. 4y) to cause a pull-down menu 960a to appear and then selecting a Create Wizard 960b option from the pull-down menu. The administrator then begins using the particular sequence of screens that they wish to turn into a custom wizard and the custom wizard tool records this sequence of screens. For example, the administrator may begin by selecting a port within device mimic 896a, clicking the right mouse button and selecting the Configure SONET Paths option to cause the SONET Path configuration wizard 944 (Fig. 5b) to appear. The custom wizard tool records the first screen to be included in the new custom wizard as the SONET Path configuration wizard screen 944. After filling in the appropriate data for the current port configuration, the

administrator presses the OK button and the SONET Paths tab 942 (Fig. 5h) appears. The custom wizard records the SONET Paths tab screen as the next screen in the new custom wizard. The administrator may then select Virtual ATM interfaces tab 947 (Fig. 5s) to cause this tab to be displayed. Again, the custom navigator records this screen as the next screen in the new custom wizard.

The administrator may continue to select further screens to add to the new custom wizard (for example, by selecting an ATM interface from device tree 947a and then selecting the Add button 947b to cause the Add V-ATM Interface dialog box 950 (Fig. 5t) to appear) or, if the administrator is finished sequencing through all of the screens that the administrator wants added to the new custom wizard, the administrator again selects Custom Wizard menu button 960 (Fig. 4y) and then selects a Finish Wizard option 960c. This causes a dialog box 960d to appear, and the administrator enters a name (e.g., test) for the custom wizard just created.

To access a custom wizard, the administrator again selects Custom Wizard 960 menu button and then selects a Select Wizard option 960e to cause an inventory 960f of custom wizards to be displayed. The administrator then selects a custom wizard (e.g., test), and the custom wizard automatically presents the administrator with the first screen of that wizard. In the continuing example, the custom navigator presents SONET Path configuration wizard screen 961 (Fig. 4z). Since the administrator may start a custom wizard from any screen within GUI 895, SONET Path wizard screen 961 is different from the screen 944 displayed in Fig. 5b because SONET line data 961a (i.e., slot, port, type) is not provided. That is, the administrator may not have selected a particular SONET Path to configure prior to selecting the custom wizard. Hence, the SONET line data is blank and the administrator must fill this in. After the administrator enters and/or modifies the SONET line data and any other data within the first screen, the administrator selects a Next button 961b (or an OK button) to move to the next screen in the sequence of screens defined by the custom wizard. In the next and subsequent screens, the administrator may also select a Back button to return to a previous screen within the custom wizard screen sequence. Thus, the custom wizard tool allows an administrator to

make their provisioning tasks more efficient by defining preferred screen sequences for each task.

#### Off-Line Configuration:

There may be times when a network manager / administrator wishes to jump-start initial configuration of a new network device before the network device is connected into the network. For example, a new network device may have been purchased and be in the process of being delivered to a particular site. Generally, a network manager will already know how they plan to use the network device to meet customer needs and, therefore, how they would like to configure the network device. Because configuring an entire network device may take considerable time once the device arrives and because the network manager may need to get the network device configured as soon as possible to meet network customer needs, many network managers would like the ability to perform preparatory configuration work prior to the network device being connected into the network.

In the current invention, network device configuration data is stored in a configuration database within the network device and all changes to the configuration database are copied in the same format to an external NMS database. Since the data in both databases (i.e., configuration and NMS) is in the same format, the present invention allows a network device to be completely configured “off-line” by entering all configuration data into an NMS database using GUI 895 in an off-line mode. When the network device is connected to the network, the data from the NMS database is reliably downloaded to the network device as a group of SQL commands using a relational database transaction. The network device then executes the SQL commands to enter the data into the internal configuration database, and through the active query process (described below), the network device may be completely and reliably configured.

Referring to Fig. 6a, the network manager begins by selecting Devices branch 898a in navigation tree 898, clicking the right mouse button to cause pop-up menu 898c to appear and selecting the Add Devices option causing dialog box 898d (Fig. 6b) to be displayed.

The network manager then enters the intended IP address or DNS name (e.g., 192.168.9.201) of the new network device into field 898e and de-selects a Manage device in on-line mode option 898k – that is, the network manager moves the cursor over box 898l and clicks the left mouse button to clear box 898l. De-selecting the Manage device in on-line mode option indicates that the network device will be configured in off-line mode. The network manager then selects Add button 898f to cause dialog box 898d to add the IP address to window 898g (Fig. 6c). However, in this example, box 898m is blank indicating the network device is to be configured off-line.

Referring to Fig. 6d, the new network device (e.g., 192.168.9.201) is now added to the list of devices 898b to be managed. However, the icon includes a visual indicator 898n (e.g., red “X”) indicating the off-line status of the device. To begin off-line configuration, the network manager selects the new device. Since the NMS client and NMS server are not connected to the actual network device, no configuration data may be read from the network device’s configuration database. The network manager must, therefore, populate a device mimic with modules representing the physical inventory that the network device will include. To do this, the network manager begins by clicking on the right mouse button to display pop-up menu 898o, and selects the Add Chassis option to cause a device mimic 896a (Fig. 6e) to be displayed in window 896b including only a chassis. All slots in the chassis may be empty and visually displayed, for example, in a gray or light color. Alternatively, particular modules that are required for proper network device operation may be automatically included in the chassis. If more than one chassis type is available, a dialog box would appear and allow the network manager to select a particular chassis. In the current example, only one chassis is available and is automatically displayed when the network manager selects the Add Chassis option.

Again, the cursor provides context sensitive pop-up windows. For example, the network manager may move the cursor over a particular slot (e.g., 896c, Fig. 6e) to cause a pop-up window (e.g., 896d) to appear and describe the slot (e.g., Empty Forwarding Processor Slot Shelf 3/Slot 1). The network manager may then select an empty slot (e.g., 896c, Fig. 6f) to cause the device mimic to highlight that slot, click the right mouse button to cause



modules. To add a different type of universal port card, the network manager will again select the empty slot, click on the right mouse button, select the Add Module button from the pop-up menu and then select the appropriate type of universal port card from the dialog box.

Once the network manager is finished adding appropriate modules into the empty slots such that the device mimic represents the physical hardware that will be present in the new network device, then the network manager may configure / provision services within the network device. Off-line configuration is the same as on-line configuration, however, instead of sending the configuration data to the configuration database within the network device, the NMS server stores the configuration data in an external NMS database. After the network device arrives and the network manager connects the network device's ports into the network, the network manager selects the device (e.g., 192.168.9.201, Fig. 6n), clicks the right mouse button to cause pop-up menu 868o to appear and selects the Manage On-line option.

The NMS client notifies the NMS server that the device is now to be managed on-line. The NMS server first reconciles the physical configuration created by the network manager and stored in the NMS database against the physical configuration of the actual network device and stored in the internal configuration database. If there are any mismatches, the NMS server notifies the NMS client, which then displays any discrepancies to the network manager. After the network manager fixes any discrepancies, the network manager may again select the Manage On-Line option in pop-up menu 898o. If there are no mis-matches between the physical device tables in the NMS database and the configuration database, then the NMS server reconciles all service provisioning data in the NMS database against the service provisioning data in the configuration database. In this example, the network device is new and thus, the configuration database has no service provisioning data. Thus, the reconciliation will be successful.

The NMS server then instructs the network device to stop replication between the primary configuration database within the network device and the backup configuration

database within the network device. The NMS server then pushes the NMS database data into the backup configuration database, and then instructs the network device to switchover from the primary configuration database to the backup configuration database. If any errors occur after the switchover, the network device may automatically switch back to the original primary configuration database. If there are no errors, then the network device is quickly and completely configured to work properly within the network while maximizing network device availability.

In the previous example, the network manager configured one new network device off-line. However, a network manager may configure many new network devices off-line. For example, a network manager may be expecting the receipt of five or more new network devices. Referring to Fig. 60, to simplify the above process, a network manager may select an on-line device (e.g., 192.168.9.202) or off-line device (e.g., 192.168.9.201) by pressing and holding the left mouse button down, dragging an icon over to a newly added off-line device (e.g., 192.168.203) and dropping the icon over the newly added off-line device by releasing the left mouse button. The NMS client notifies the NMS server to copy the configuration data from the NMS database associated with the first network device (e.g., 192.168.9.202 or 192.168.9.201) to a new NMS database associated with the new network device and to change the data in the new NMS database to correspond to the new network device. The network manager may then select the new network device and modify any of the configuration data, as described above, to reflect the current network device requirements. As a result, off-line mode configuration is also made more efficient.

A network manager may also choose to re-configure an operational device in off-line mode without affecting the operation of the network device. For example, the network manager may want to add one or more new modules or provision services in a network device during a time when the network sees the least amount of activity, for example, midnight. Through the off-line mode, the network manager may prepare the configuration data ahead of time.



Referring to Fig. 6p, the network manager may select an operational network device (e.g., 192.168.9.202), click on the right mouse button to cause pop-up menu 898o to appear and select the Manage On-Line option, which de-selects the current on-line mode and causes the GUI to enter an off-line mode for this device. Although the GUI has entered the off-line mode, the network device is still operating normally. The network manager may then add one or more modules and/or provision services as described above just as if the GUI were still in on-line mode, however, all configuration changes are stored by the NMS server in the NMS database corresponding to the network device instead of the network device's configuration database. Alternatively, when the NMS server is notified that a network device is to be managed off-line, the NMS server may copy the NMS database data to a temporary NMS database and store all off-line configuration changes there. When the network manager is ready (i.e., at the appropriate time and/or after adding any new modules to the network device) to download the configuration changes to the operational network device, the network manager again selects the network device (e.g., 192.168.9.202), clicks on the right mouse button to cause pop-up menu 898a to appear and selects the Manage On-Line option.

The NMS client notifies the NMS server that the device is now to be managed on-line. The NMS server first reconciles the physical configuration stored in the NMS database (or the temporary NMS database) against the physical configuration of the actual network device stored in the internal configuration database. If there are any mis-matches, the NMS server notifies the NMS client, which then displays any discrepancies to the network manager. After the network manager fixes any discrepancies, the network manager may again select the Manage On-Line option in pop-up menu 898o. If there are no mis-matches between the physical device tables in the NMS database and the configuration database, then the NMS server reconciles all service provisioning data in the NMS database (or the temporary NMS database) against the service provisioning data in the configuration database. If any conflicts are discovered, the NMS server notifies the NMS client, which displays the discrepancies to the network manager. After fixing any discrepancies, the network manager may again select the Manage On-Line option in pop-up menu 898o.

If there are no conflicts, the NMS server instructs the network device to stop replication between the primary configuration database within the network device and the backup configuration database within the network device. The NMS server then pushes the NMS database data into the backup configuration database, and then instructs the network device to switchover from the primary configuration database to the backup configuration database. If any errors occur after the switchover, the network device may automatically switch back to the original primary configuration database. If there are no errors, then the network device is quickly re-configured to work properly within the network.

Off-line configuration, therefore, provides a powerful tool to allow network managers to prepare configuration data prior to actually implementing any configuration changes. Such preparation, allows a network manager to carefully configure a network device when they have time to consider all their options and requirements, and once the network manager is ready, the configuration changes are implemented quickly and efficiently.

#### FCAPS Management:

Fault, Configuration, Accounting, Performance and Security (FCAPS) management are the five functional areas of network management as defined by the International Organization for Standardization (ISO). Fault management is for detecting and resolving network faults, configuration management is for configuring and upgrading the network, accounting management is for accounting and billing for network usage, performance management is for overseeing and tuning network performance, and security management is for ensuring network security. Referring to Fig. 6a, GUI 895 provides a status button 899a-899f for each of the five FCAPS. By clicking on one of the status buttons, a status window appears and displays the status associated with the selected FCAPS button to the network administrator. For example, if the network administrator clicks on the F status button 899a, a fault event summary window 900 (Fig. 6b) appears and displays the status of any faults.

Each FCAP button may be colored according to a hierarchical color code where, for example, green means normal operation, red indicates a serious error and yellow indicates a warning status. Today there are many NMSs that indicate faults through color coded icons or other graphics. However, current NMSs do not categorize the errors or warnings into the ISO five functional areas of network management – that is, FCAPS. The color-coding and order of the FCAPS buttons provide a “status bar code” allowing a network administrator to quickly determine the category of error or warning and quickly take action to address the error or warning.

As with current NMSs, a network administrator may actively monitor the FCAPS buttons by sitting in front of the computer screen displaying the GUI. Unfortunately, network administrators do not have time to actively monitor the status of each network device — passive monitoring is required. To assist passive monitoring, the FCAPS buttons may be enlarged or “stretched” to fill a large portion of the screen, as shown in Fig. 6c. The FCAPS buttons may be stretched in a variety of ways, for example, a stretch option in a pull down menu may be selected or a mouse may be used to drag and drop the borders of the FCAPS buttons. Stretching the FCAPS buttons allows a network administrator to view the status of each FCAP button from a distance of 40 feet or more. Once stretched, each of the five OSI management areas can be easily monitored at a distance by looking at the bar-encoded FCAPS strip. The “stretchy FCAPS” provide instant status recognition at a distance.

The network administrator may set the FCAPS buttons to represent a single network device or multiple network devices or all the network devices in a particular network. Alternatively, the network administrator may have the GUI display two or more FCAPS status bars each of which represents one or more network devices.

Although the FCAPS buttons have been described as a string of multiple stretched bars, many different types of graphics may be used to display FCAPS status. For example, different colors may be used to represent normal operation, warnings and errors, and additional colors may be added to represent particular warnings and/or errors. Instead of

a bar, each letter (e.g., F) may be stretched and color-coded. Instead of a solid color, each FCAPS button may repeatedly flash or strobe a color. For example, green FCAPS buttons may remain solid (i.e., not flashing) while red errors and yellow warnings are displayed as a flashing FCAPS button to quickly catch a network administrator's attention. As another example, green / normal operation FCAPS buttons may be a different size relative to yellow / warnings and red / errors FCAPS buttons. For example, an FCAPS button may be automatically enlarged if status changes from good operation to a warning status or an error status. In addition, the FCAPS buttons may be different sizes to allow the network administrator to distinguish between each FCAPS button from a further distance. For example, the buttons may have a graduated scale where the F button is the largest and each button is smaller down to the S button, which is the smallest. Alternatively, the F button may be the smallest while the S button is the largest, or the A button in the middle is the largest, the C and P buttons are smaller and the F and S buttons are smallest. Many variations are possible for quickly alerting a network administrator of the status of each functional area.

### Profiles:

Profiles may be used by the NMS client to provide individual users (e.g., network managers and customers) with customized graphical user interfaces (GUIs) or views of their network and with defined management capabilities. For example, some network managers are only responsible for a certain set of devices in the network. Displaying all network devices makes their management tasks more difficult and may inadvertently provide them with management capabilities over network devices for which they are not responsible or authorized to perform. With respect to customers, profiles limit access to only those network devices in a particular customer's network. This is crucial to protecting the proprietary nature of each customer's network. Profiles also allow each network manager and customer to customize the GUI into a presentation format that is most efficient or easy for them to use. For example, even two users with access to the same network devices and having the same management capabilities may have different GUI customizations through their profiles. In addition, profiles may be used to provide other important information, for example, SNMP community strings to allow an NMS

server to communicate with a network device over SNMP, SNMP retry and timeout values, and which NMS servers to use, for example, primary and secondary servers may be identified.

A network administrator is typically someone who powers up a network device for the first time, installs necessary software on the new network device as well as installs any NMS software on an NMS computer system, and adds any additional hardware and/or software to a network device. The network administrator is also the person that attaches physical network cables to network device ports. The first time GUI 895 is displayed to a network administrator, an NMS client uses a profile including a set of default values. Referring again to Fig. 6a, the administrator may change the default values in his profile by selecting (e.g., clicking on) a profile selection 902 in a navigation tree / menu 898. This causes the NMS client to display a profiles tab 903 (Fig. 6d) on the screen. The profile tab displays any existing profiles 904. The first time the profile tab appears only the network administrator's profile is displayed as no other profiles yet exist.

To save a network manager's time, the profiles tab may also include a copy button 906. By selecting a profile 904 and clicking on the copy button, an existing profile is copied. The network manager may then change the parameters within the copied profile. This is helpful where two user profiles are to include the same or similar parameters.

To change the parameters in the network administrator's profile or any other existing profile, including a copied profile, the user clicks on one of the profiles 904. To add a new profile, the user clicks on an Add button 905. In either case, the NMS client displays a profile dialog box 907 (Fig. 6e) on the screen. Through the profile dialog box, a user's user name 908a, password 908b and confirmed password 908c may be added. The confirm password field is used to assure that the password was entered properly in the password field. The password and confirmed password may be encrypted strings used for user authentication. These fields will be displayed as asterisks on the screen. Once added, a user simply logs on to an NMS client with this user name and password and the NMS client displays the GUI in accordance with the other parameters of this profile.

A group level access field 908d enables/disables various management capabilities (i.e., functionality available through the NMS client). Clicking on the group level access field may provide a list of available access levels. In one embodiment, access levels may include administrator, provisioner and customer, with administrator having the highest level of management capabilities and customer having the lowest level of management capabilities (described in more detail below). In one embodiment, users can create profiles for other users at or below their own group access level. For example, a user at the provisioner access level can create user profiles for users at either the provisioner or customer level but cannot create an administrator user profile.

A description may be added in a description field 908e, including a description of the user, phone number, fax number and/or e-mail address. A group name may be added to group field 908f, and a list of network device IP addresses may be provided in a device list field 908g. Alternatively, a domain name server (DNS) name may be provided and a host look up may be used to access the IP address of the corresponding device. Where a group name is provided, the list of network devices is associated with the group such that if the same group name is assigned to multiple user profiles, the users will be presented with the same view – that is, the same list of network devices in device list field 908g. For example, users from the same customer may share a group name corresponding to that customer. A wildcard feature is available for the group field. For example, perhaps an \* or ALL may be used as a wildcard to indicate that a particular user is authorized to see all network devices. In most instances, the wildcard feature will only be used for a high-level network administrator. The list of devices indicates which network devices the user may manage or view, for example, configuration status and statistics data may be viewed.

Within a profile certain policy flags may also be set. For example, a flag 908h may be set to indicate that the user is not allowed to change his/her password, and an account disable flag 908i may be set to disable a particular profile / account. In addition, a flag 908j may

be set to allow the user to add network device IP addresses to device list field 908g, and a number may be added to a timeout field 908k to specify a number of minutes after which a user will be automatically logged out due to inactivity. A zero in this field or no value in this field may be used to indicate unlimited activity, that is, the user will never be automatically logged out.

The profile may also be used to indicate which NMS servers the NMS client should communicate with. An IP address may be added to a primary server field 908l and a secondary server field 908m. If the primary server fails, the client will access the secondary server. A port number is added to primary server port field 908n and to secondary server port field 908o to indicate the particular ports that should be used for RMI connectivity to the primary and secondary NMS servers.

Additional fields may be added to the device list to provide more information. For example, a read field 908p may be used to indicate the SNMP community string to be used to allow the NMS server to communicate with the network device over SNMP. The SNMP connection may be used to retrieve statistical data from the network device. In addition, a read/write field 908q may be used to indicate an SNMP community string to allow the NMS server to configure the network device and/or provision services. The profile may also include a retry field 908r and a timeout field 908s to provide SNMP retry and timeout values. Many different fields may be provided in a profile.

Instead of providing all the parameters and fields in a single profile dialog box, they may be separated into a variety of a tabbed dialog boxes (Figs. 6f-6i). The tabbed dialog boxes may provide better scalability and flexibility for future needs.

In one embodiment, an administrator level user has both read and write access to the physical and logical objects of the NMS client. Thus, all screens and functionality are available to an administrator level user, and an administrator after physically attaching an

external network attachment to a particular network device port may then enable that port and provision SONET paths on that port. All screens are available to a provisioner level user, however, they do not have access to all functionality as they are limited to read-only access of physical objects. For example, a provisioner can see SONET ports available on a device and can provision SONET paths on a port, but the provisioner cannot enable/disable a SONET port. In other words, a provisioner's power begins at the start of logical objects (not physical objects), for example, SONET paths, ATM interfaces, virtual ATM interfaces, and PVCs, and continues through all the configuration aspects of any object or entity that can be stacked on top of either a SONET path or ATM interface. A customer level user has read-only access to logical entities and only those logical entities corresponding to their group name or listed in the device list field. A customer may or may not have access to Fault, Configuration, Accounting, and Security categories of FCAPS relative to their devices.

A customer may install an NMS client at a customer site or, preferably, the customer will use a web browser to access the NMS client. To use the web browser, a service provider gives the customer an IP address corresponding to the service provider's site. The customer supplies the IP address to their web browser and while at the service provider site, the customer logs in with their username and password. The NMS client then displays the customer level GUI corresponding to that username and password.

Referring to Fig. 6j, a user preference dialog box 909 may be used to customize the GUI into a presentation format that is most efficient or easy for a user to work with. For example, show flags may be used to add tool tips (flag 910a), add horizontal grid lines on tables (flag 910b), add vertical grid lines on tables (flag 910c) and add bookmarks / short cuts (e.g., create a short cut to a PVC dialog box). Look and feel flags may also be used to make the GUI appear as a JAVA GUI would appear (flag 911a) or as a native application, for example, Windows, Windows/NT or Motif, GUI would appear (flag 911b).



### Power-Up:

Referring again to Fig. 1, on power-up, reset or reboot, the processor on each board (central processor and each line card) downloads and executes boot-strap code (i.e., minimal instances of the kernel software) and power-up diagnostic test code from its local memory subsystem. After passing the power-up tests, processor 24 on central processor 12 then downloads kernel software 20 from persistent storage 21 into non-persistent memory in memory subsystem 28. Kernel software 20 includes operating system (OS), system services (SS) and modular system services (MSS).

In one embodiment, the operating system software and system services software are the OSE operating system and system services from Enea OSE Systems, Inc. in Dallas, Texas. The OSE operating system is a pre-emptive multi-tasking operating system that provides a set of services that together support the development of distributed applications (i.e., dynamic loading). The OSE approach uses a layered architecture that builds a high level set of services around kernel primitives. The operating system, system services, and modular system services provide support for the creation and management of processes; inter-process communication (IPC) through a process-to-process messaging model; standard semaphore creation and manipulation services; the ability to locate and communicate with a process regardless of its location in the system; the ability to determine when another process has terminated; and the ability to locate the provider of a service by name.

These services support the construction of a distributed system wherein applications can be located by name and processes can use a single form of communication regardless of their location. By using these services, distributed applications may be designed to allow services to transparently move from one location to another such as during a fail over.

The OSE operating system and system services provide a single inter-process communications mechanism that allows processes to communicate regardless of their location in the system. OSE IPC differs from the traditional IPC model in that there are no explicit IPC queues to be managed by the application. Instead each process is assigned



master MCD 38 are executed by central processor 12 while slave SRMs 37a-37n and slave MCDs 39a-39n are executed on each board (central processor 12 and each line card 16a-16n). The SRM and MCD work together and use their assigned view ids and APIs to load the appropriate software drivers on each board and to configure computer system 10.

Also within the modular system services is a configuration service program 35 that downloads a configuration database program 42 and its corresponding DDL file from persistent storage into non-persistent memory 40 on central processor 12. In one embodiment, configuration database 42 is a Polyhedra database from Polyhedra, Inc. in the United Kingdom.

#### Hardware Inventory and Set-Up:

Master MCD 38 begins by taking a physical inventory of computer system 10 (over the I<sup>2</sup>C bus) and assigning a unique physical identification number (PID) to each item. Despite the name, the PID is a logical number unrelated to any physical aspect of the component being numbered. In one embodiment, pull-down/pull-up resistors on the chassis mid-plane provide the number space of Slot Identifiers. The master MCD may read a register for each slot that allows it to get the bit pattern produced by these resistors. MCD 38 assigns a unique PID to the chassis, each shelf in the chassis, each slot in each shelf, each line card 16a-16n inserted in each slot, and each port on each line card. (Other items or components may also be inventoried.)

Typically, the number of line cards and ports on each line card in a computer system is variable but the number of chasses, shelves and slots is fixed. Consequently, a PID could be permanently assigned to the chassis, shelves and slots and stored in a file. To add flexibility, however, MCD 38 assigns a PID even to the chassis, shelves and slots to allow the modular software architecture to be ported to another computer system with a different physical construction (i.e., multiple chasses and / or a different number of shelves and slots) without having to change the PID numbering scheme.





configuration database and NMS database are downloaded and upgraded (as described below) without re-booting the computer system.

#### Network Management System (NMS):

Referring to Fig. 9a, as described above, a user / network administrator of computer system 10 works with network management system (NMS) software 60 to configure computer system 10. In the embodiment described below, NMS 60 runs on a personal computer or workstation 62 and communicates with central processor 12 over Ethernet network 32 (out-of-band). Instead, the NMS may communicate with central processor 12 over data path 34 (Fig. 1, in-band). Alternatively (or in addition as a back-up communication port), a user may communicate with computer system 10 through a console interface / terminal (840, Fig. 2a) connected to a serial line 66 connecting to the data or control path using a command line interface (CLI) protocol. Instead, NMS 60 could run directly on computer system 10 provided computer system 10 has an input mechanism for the user.

During installation, an NMS database 61 is established on, for example, work-station 62 using a DDL executable file corresponding to the NMS database. The DDL file may be downloaded from persistent storage 21 in computer system 10 or supplied separately with other NMS programs as part of an NMS installation kit. The NMS database mirrors the configuration database through an active query feature (described below). In one embodiment, the NMS database is an Oracle database from Oracle Corporation in Boston, Massachusetts.

The NMS and central processor 12 pass control and data over Ethernet 32 using, for example, the Java Database Connectivity (JDBC) protocol. Use of the JDBC protocol allows the NMS to communicate with the configuration database in the same manner that it communicates with its own internal storage mechanisms, including the NMS database. Changes made to the configuration database are passed to the NMS database to ensure that both databases store the same data. This synchronization process is much more efficient, less error-prone and timely than older methods that require the NMS to

periodically poll the network device to determine whether configuration changes have been made. In these systems, NMS polling is unnecessary and wasteful if the configuration has not been changed. Additionally, if a configuration change is made through some other means, for example, a command line interface, and not through the NMS, the NMS will not be updated until the next poll, and if the network device crashes prior to the NMS poll, then the configuration change will be lost. In computer system 10, however, command line interface changes made to configuration database 42 are passed immediately to the NMS database through the active query feature ensuring that the NMS, through both the configuration database and NMS database, is immediately aware of any configuration changes.

#### Asynchronously Providing Network Device Management Data:

Typically, work-station 62 is coupled to many network computer systems, and NMS 60 is used to configure and manage each of these systems. In addition to configuring each system, the NMS also interprets management data gathered by each system relevant to each system's network accounting data, statistics, security and fault logging and presents this to the user. In current systems, two distributed carefully synchronized processes are used to move data from a network system/device to the NMS. The processes are synchronized with each other by having one or both processes maintain the state of the other process. To avoid the problems associated with using two synchronized processes, in the present invention, internal network device management subsystem processes are made asynchronous with external management processes. That is, neither the internal nor external processes maintain each other's state and all processes operate independently of the other processes. This also minimizes or prevents data loss (i.e., lossless system), which is especially important for revenue generating accounting systems.

In addition, instead of having the NMS interpret each network device's management data in the same fashion, flexibility is added by having each system send the NMS (e.g., data collector server 857, Fig. 2a) class files 410 including compiled source code indicating how its management data should be interpreted. Thus, the NMS effectively "learns" how to process (and perhaps display) management data from the network device via the class

file. Through the reliable File Transfer Protocol (FTP), management subsystem processes 412 running on central processor 12 push data summary files 414 and binary data files 416 to the NMS. Each data summary file indicates the name of the class file the NMS should use to interpret a corresponding binary data file. If the computer system has not already done so, it pushes the class file to the NMS. In one embodiment, the management subsystem processes, class files and NMS processes are JAVA programs, and JAVA Reflection is used to dynamically load the data-specific application class file and process the data in the binary data file. As a result, a new class file can be added or updated on a network device without having to reboot or upgrade the network device or the NMS. The computer system simply pushes the new class file to the NMS. In addition, the NMS can use different class files for each network device such that the data gathered on each device can be particularized to each device.

Referring to Fig. 9b, in one embodiment, the management subsystem 412 (Fig. 9a) is broken into two pieces: a usage data server (UDS) 412a and a file transfer protocol (FTP) client 412b. The UDS is executed on internal processor control card 542a (see also Figs. 41b and 42) while the FTP client is executed on external processor control card 542b (see also Figs. 41a and 42). Alternatively, in a network device with one processor control card or a central processor control card, both the UDS and FTP client may be executed on that one card. When each device driver, for example, SONET driver 415a-415n and ATM driver 417a-417n (only SONET driver 415a and ATM driver 417a are shown for convenience), within network device 540 is built, it links in a usage data monitoring library (UDML). When device drivers are first started, upgraded or re-booted, the UDML causes each device driver to register with the UDS providing one or more string names corresponding to types of data that the device driver will send to the UDS. For example, each ATM driver may register "Acct\_PVC" to track permanent virtual circuit statistics, "Acct\_SVC" to track soft permanent virtual circuit statistics, "Vir\_Intf" to track quality of service (QoS) statistics corresponding to virtual interfaces, and "Bw\_Util" to track bandwidth utilization. As another example, each SONET driver may register "Section" to track section statistics, "Line" to track line statistics and "Path" to track path statistics.



The UDML also provides each device driver with a polling timer to cause each driver to periodically poll its hardware for statistical/accounting data. The UDML also causes each driver to put the binary data in a particular format and send this binary data to the UDS with one of the registered string names. For each poll, the UDS combines the data sent from each device driver with the same string name into a binary data file (e.g., binary data files 416a-416n) with that string name and stores the binary data file. The binary data file may be stored in, for example, a hard drive 421 located on internal control processor 542a. Preferably, the data is maintained in binary form to keep the data files smaller than translating it into other forms such as ASCII. It should be understood, however, that the UDS may translate the binary data into ASCII or any other format before storing it on hard drive 421.

Preferably, polls for different statistical data are scheduled at different times to load balance the amount of statistical traffic across the control plane. For example, each ATM driver polls and sends data to the UDS corresponding to PVC accounting statistics (i.e., Acct\_PVC) at a first time, each ATM driver polls and sends data to the UDS corresponding to SPVC accounting statistics (i.e., Acct\_SPVC) at a second time, and each ATM driver and each SONET driver polls and sends data to the UDS corresponding to other statistics at other different times.

For each binary data file, the UDS creates a data summary file (e.g., data summary files 414a-414n) and stores it in, for example, hard drive 421. The data summary file defines the binary file format, including the type based on the string name, the length, the number of records and the version number. The UDS does not need to understand the binary data sent to it by each of the device drivers. The UDS need only combine data corresponding to similar string names into the same file and create a summary file based on the string name and the amount of data in the binary data file. The version number is passed to the UDS by the device driver, and the UDS includes the version number in the data summary file.

Periodically, FTP client 412b asynchronously reads each binary data file and corresponding data summary file from hard drive 421. Preferably, the FTP client reads these files from the hard drive through an out-of-band Ethernet connection, for example, Ethernet 32 (Fig. 1). Alternatively, the FTP client may read these files through an in-band data path 34 (Fig. 1). The FTP client then uses an FTP push to send the binary data file to a file system 425 accessible by the data collector server and, preferably local to the data collector server. The FTP client then uses another FTP push to send the data summary file to the local file system. Since binary data files may be very long and an FTP push of a binary data file may take some time, the data collector server may periodically search the local file system for data summary files. The data collector server may then attempt to open a discovered data summary file. If the data collector server is able to open the file, then that indicates that the FTP push of the data summary file is complete, and since the data summary file is pushed after the binary data file, the data collector server's ability to open the data summary file may be used as an indication that a new binary data file has been completely received. Since data summary files are much smaller than binary data files, having the data collector server look for and attempt to open data summary files instead of binary data files minimizes the thread wait within the data collector server.

In one embodiment, the data collector server is a JAVA program, and each different type of binary data file has a corresponding JAVA class file (e.g., class file 410a) that defines how the data collector server should process the binary data file. When a device driver is loaded into the network device, a corresponding JAVA class file is also loaded and stored in hard drive 421. The FTP client periodically polls the hard drive for new JAVA class files and uses an FTP push to send them to file system 425. The data collector server uses the binary file type in the data summary file to determine which JAVA class file it should use to interpret the binary data file. The data collector server then converts the binary data into ASCII or AMA/BAF format and stores the ASCII or AMA/BAF files in the file system. The data collector server may use a set of worker threads for concurrency.

As described, the data collector server is completely independent of and asynchronous with the FTP client, which is also independent and asynchronous of the UDS. The separation of the data collector server and FTP client avoids data loss due to process synchronization problems, since there is no synchronization, and reduces the burden on the network device by not requiring the network device to maintain synchronization between the processes. In addition, if the data collector server goes down or is busy for some time, the FTP client and UDS continue working and continue sending binary data files and data summary files to the file system. When the data collector server is again available, it simply accesses the data summary files and processes the binary files as described above. Thus, there is no data loss and the limited storage capacity within the network device is not strained by storing data until the data collector server is available. In addition, if the FTP client or UDS goes down, the data collector server may continue working.

An NMS server (e.g., NMS server 851a), which may or may not be executing on the same computer system 62 as the data collector server, may periodically retrieve the ASCII or AMA/BAF files from the file system. The files may represent accounting, statistics, security, logging and/or other types of data gathered from hardware within the network device. The NMS server may also access the corresponding class files from the file system to learn how the data should be presented to a user, for example, how a graphical user interface (GUI) should be displayed, what data and format to display, or perhaps which one of many GUIs should be used. The NMS server may use the data to, for example, monitor network device performance, including quality of service guarantees and service level agreements, as well as bill customers for network usage. Alternatively, a separate billing server 423a or statistics server 423b, which may or may not be executing on the same computer system 62 as the data collector server and/or the NMS server, may periodically retrieve the ASCII or AMA/BAF files from the file system in order to monitor network device performance, including quality of service guarantees and service level agreements, and/or bill customers for network usage. One or more of the data collector server, the NMS server, the billing server and the statistics server may be combined into one server. Moreover, management files created by the data collector

server may be combined with data from the configuration or NMS databases to generate billing records for each of the network provider's customers.

The data collector server may convert the ASCII or AMA/BAF files into other data formats, for example, Excel spread sheets, for use by the NMS server, billing server and/or statistics server. In addition, the application class file for each data type may be modified to go beyond conversion, including direct integration into a database or an OSS system. For example, many OSS systems use a Portal billing system available from Portal Software, Inc. in Cupertino, CA. The JAVA class file associated with a particular binary data file and data summary file may cause the data collector server to convert the binary data file into ASCII data and then issue a Portal API call to give the ASCII data directly to the Portal billing system. As a result, accounting, statistics, logging and/or security data may be directly integrated into any other process, including third party processes, through JAVA class files.

Through JAVA class files, new device drivers may be added to a network device without having to change UDS 412a or FTP client 412b and without having to re-boot the network device and without having to upgrade/modify external processes. For example, a new forwarding card (e.g., forwarding card 552a) may be added to an operating network device and this new forwarding card may support MPLS. An MPLS device driver 419, linked within the UDML, is downloaded to the network device as well as a corresponding class file (e.g., class file 410e). When the FTP client discovers the new class file in hard drive 421, it uses an FTP push to send it to file system 425. The FTP client does not need to understand the data within the class file it simply needs to push it to the file system. Just as with other device drivers, the UDML causes the MPLS driver to register appropriate string names with the UDS and poll and send data to the UDS with a registered string name. The UDS stores binary data files (e.g., binary data file 416e) and corresponding data summary files (e.g., data summary file 414e) in the hard drive without having to understand the data within the binary data file. The FTP client then pushes these files to the file system again without having to understand the data. When the data summary file is discovered by the data collector server, the data collector server



Referring again to Fig. 9a, initially, NMS 60 reads card table 47 and port table 49 to determine what hardware is available in computer system 10. The NMS assigns a logical identification number (LID) 98 (Figs. 11a and 11b) to each card and port and inserts these numbers in an LID to PID Card table (LPCT) 100 and an LID to PID Port table (LPPT) 101 in configuration database 42. Alternatively, the NMS could use the PID previously assigned to each board by the MCD. However, to allow for hardware redundancy, the NMS assigns an LID and may associate the LID with at least two PIDs, a primary PID 102 and a backup PID 104. (LPCT 100 may include multiple backup PID fields to allow more than one backup PID to be assigned to each primary PID.)

The user chooses the desired redundancy structure and instructs the NMS as to which boards are primary boards and which boards are backup boards. For example, the NMS may assign LID 30 to line card 16a -- previously assigned PID 500 by the MCD -- as a user defined primary card, and the NMS may assign LID 30 to line card 16n -- previously assigned PID 513 by the MCD -- as a user defined back-up card (see row 106, Fig. 11a). The NMS may also assign LID 40 to port 44a -- previously assigned PID 1500 by the MCD -- as a primary port, and the NMS may assign LID 40 to port 68a -- previously assigned PID 1600 by the MCD -- as a back-up port (see row 107, Fig. 11b).

In a 1:1 redundant system, each backup line card backs-up only one other line card and the NMS assigns a unique primary PID and a unique backup PID to each LID (no LIDs share the same PIDs). In a 1:N redundant system, each backup line card backs-up at least two other line cards and the NMS assigns a different primary PID to each LID and the same backup PID to at least two LIDs. For example, if computer system 10 is a 1:N redundant system, then one line card, for example, line card 16n, serves as the hardware backup card for at least two other line cards, for example, line cards 16a and 16b. If the NMS assigns an LID of 31 to line card 16b, then in logical to physical card table 100 (see row 109, Fig. 11a), the NMS associates LID 31 with primary PID 501 (line card 16b) and backup PID 513 (line card 16n). As a result, backup PID 513 (line card 16n) is associated with both LID 30 and 31.



PID 513 is line card 16n. The master SRM then notifies slave SRM 37b on line card 16a that it has been assigned LID 30 and is a primary line card, SRM 37c on line card 16b that it has been assigned LID 31 and is a primary line card and SRM 37o on line card 16n that it has been assigned LIDs 30 and 31 and is a backup line card. All three slave SRMs 37b, 37c and 37o then set up active queries with configuration database 42 to insure that they are notified of any software load records (SLRs) created for their LIDs. A similar process is followed for the LIDs assigned to each port.

The NMS informs the user of the hardware available in computer system 10. This information may be provided as a text list, as a logical picture in a graphical user interface (GUI), or in a variety of other formats. The user then uses the GUI to tell the NMS (e.g., NMS client 850a, Fig. 2a) how they want the system configured.

The user will select which ports (e.g., 44a-44d, 46a-46f, 68a-68n) the NMS should enable. There may be instances where some ports are not currently needed and, therefore, not enabled. The user also needs to provide the NMS with information about the type of network connection (e.g., connection 70a-70d, 72a-72f, 74a-74n). For example, the user may want all ports 44a-44d on line card 16a enabled to run ATM over SONET. The NMS may start one ATM application to control all four ports, or, for resiliency, the NMS may start one ATM application for each port. Alternatively, each port may be enabled to run a different protocol (e.g., MPLS, IP, Frame Relay).

In the example given above, the user must also indicate the type of SONET fiber they have connected to each port and what paths to expect. For example, the user may indicate that each port 44a-44d is connected to a SONET optical fiber carrying an OC-48 stream. A channelized OC-48 stream is capable of carrying forty-eight STS-1 paths, sixteen STS-3c paths, four STS-12c paths or a combination of STS-1, STS-3c and STS-12c paths. A clear channel OC-48c stream carries one concatenated STS-48 path. In the example, the user may indicate that the network connection to port 44a is a clear channel OC-48 SONET stream having one STS-48 path, the network connection to port 44b is a channelized OC-48 SONET stream having three STS-12c paths (i.e., the SONET fiber is





The service endpoint managers (SEMs) running on each board establish active queries with the configuration database for SET 76. Thus, when the NMS changes or adds to the service endpoint table (SET), the configuration database sends the service endpoint manager associated with the port PID in the SET a change notification including information on the change that was made. In the continuing example, configuration database 42 notifies SEM 96a that SET 76 has been changed and that SE 1 was assigned to port 44a (PID 1500). Configuration database 42 notifies SEM 96b that SE 2, 3, and 4 were assigned to port 44b (PID 1501), SEM 96c that SE 5 and 6 were assigned to port 44c (PID 1502) and SEM 96d that SE 7, 8, and 9 were assigned to port 44d (PID 1503). When a service endpoint is assigned to a port, the SEM associated with that port passes the assigned SE number to the port driver for that port using the port PID number associated with the SE number.

To load instances of software applications on the correct boards, the NMS creates software load records (SLR) 128a-128n in configuration database 42. The SLR includes the name 130 (Fig. 14) of a control shim executable file and an LID 132 for cards on which the application must be spawned. In the continuing example, NMS 60 creates SLR 128a including the executable name `atm_cntrl.exe` and card LID 30 (row 134). The configuration database detects LID 30 in SLR 128a and sends slave SRMs 37b (line card 16a) and 37o (line card 16n) a change notification including the name of the executable file (e.g., `atm_cntrl.exe`) to be loaded. The primary slave SRMs then download and execute a copy of `atm_cntrl.exe` 135 from memory 40 to spawn the ATM controllers (e.g., ATM controller 136 on line card 16a). Since slave SRM 37o is on backup line card 16n, it may or may not spawn an ATM controller in backup mode. Software backup is described in more detail below. Instead of downloading a copy of `atm_cntrl.exe` 135 from memory 40, a slave SRM may download it from another line card that already downloaded a copy from memory 40. There may be instances when downloading from a line card is quicker than downloading from central processor 12. Through software load records and the tables in configuration database 42, applications are downloaded and executed without the need for the system services, including the SRM, or any other software in the kernel to have information as to how the applications should be

configured. The control shims (e.g., atm\_cntrl.exe 135) interpret the next layer of the application (e.g., ATM) configuration.

For each application that needs to be spawned, for example, an ATM application and a SONET application, the NMS creates an application group table. Referring to Fig. 12, ATM group table 108 indicates that four instances of ATM (i.e., group number 1, 2, 3, 4) – corresponding to four enabled ports 44a-44n -- are to be started on line card 16a (LID 30). If other instances of ATM are started on other line cards, they would also be listed in ATM group table 108 but associated with the appropriate line card LID. ATM group table 108 may also include additional information needed to execute ATM applications on each particular line card. (See description of software backup below.)

In the above example, one instance of ATM was started for each port on the line card. This provides resiliency and fault isolation should one instance of ATM fail or should one port suffer a failure. An even more resilient scheme would include multiple instances of ATM for each port. For example, one instance of ATM may be started for each path received by a port.

The application controllers on each board now need to know how many instances of the corresponding application they need to spawn. This information is in the application group table in the configuration database. Through the active query feature, the configuration database notifies the application controller of records associated with the board's LID from corresponding application group tables. In the continuing example, configuration database 42 sends ATM controller 136 records from ATM group table 108 that correspond to LID 30 (line card 16a). With these records, ATM controller 136 learns that there are four ATM groups associated with LID 30 meaning ATM must be instantiated four times on line card 16a. ATM controller 136 asks slave SRM 37b to download and execute four instances (ATM 110-113, Fig. 15) of atm.exe 138.

Once spawned, each instantiation of ATM 110-113 sends an active database query to search ATM interface table 114 for its corresponding group number and to retrieve



### Template Driven Service Provisioning:

Instead of using the GUI to interactively provision services on one network device in real time, a user may provision services on one or more network devices in one or more networks controlled by one or more network management systems (NMSs) interactively and non-interactively using an Operations Support Services (OSS) client and templates. At the heart of any carrier's network is the OSS, which provides the overall network management infrastructure and the main user interface for network managers / administrators. The OSS is responsible for consolidating a diverse set of element/network management systems and third-party applications into a single system that is used, for example, to detect and resolve network faults (Fault Management), configure and upgrade the network (Configuration Management), account and bill for network usage (Accounting Management), oversee and tune network performance (Performance Management), and ensure ironclad network security (Security Management). FCAPS are the five functional areas of network management as defined by the International Organization for Standardization (ISO). Through templates one or more NMSs may be integrated with a telecommunication network carrier's OSS.

Templates are metadata and include scripts of instructions and parameters. In one embodiment, instructions within templates are written in ASCII text to be human readable. There are three general categories of templates, provisioning templates, control templates and batch templates. A user may interactively connect the OSS client with a particular NMS server and then cause the NMS server to connect to a particular device. Instead, the user may create a control template that non-interactively establishes these connections. Once the connections are established, whether interactively or non-interactively, provisioning templates may be used to complete particular provisioning tasks. The instructions within a provisioning template cause the OSS client to issue appropriate calls to the NMS server which cause the NMS server to complete the provisioning task, for example, by writing / modifying data within the network device's configuration database. Batch templates may be used to concatenate a series of templates and template modifications (i.e., one or more control and provisioning templates) to provision one or more network devices. Through the client / server based architecture,

multiple OSS clients may work with one or more NMS servers. Database view ids and APIs for the OSS client may be generated using the logical model and code generation system (Fig. 3b) to synchronize the integration interfaces between the OSS clients and the NMS servers.

Interactively, a network manager may have an OSS client execute many provisioning templates to complete many provisioning tasks. Instead, the network manager may order and sequence the execution of many provisioning templates within a batch template to non-interactively complete the many provisioning tasks and build custom services. In addition, execution commands followed by control template names may be included within batch templates to non-interactively cause an OSS client to establish connections with particular NMS servers and network devices. For example, a first control template may designate a network device to which the current OSS client and NMS server are not connected. Including an execution command followed by the first control template name in a batch template will cause the OSS client to issue calls to the NMS server to cause the NMS server to access the different network device. As another example, a second control template may designate an NMS server and a network device to which the OSS client is not currently connected. Including an execution command followed by the second control template name will cause the OSS client to set up connections to both the different NMS server and the different network device. Moreover, batch templates may include execution commands followed by provisioning template names after each execution command and control template to provision services within the network devices designated by the control templates. Through batch templates, therefore, multiple control templates and provisioning templates may be ordered and sequenced to provision services within multiple network devices in multiple networks controlled by multiple NMSs.

Calls issued by the OSS client to the NMS server may cause the NMS server to immediately provision services or delay provisioning services until a predetermined time, for example, a time when the network device is less likely to be busy. Templates may be written to apply to different types of network devices.

A “command line” interactive interpreter within the OSS client may be used by a network manager to select and modify existing templates or to create new templates. Templates may be generated for many various provisioning tasks, for example, setting up a permanent virtual circuit (PVC), a switched virtual circuit (SVC), a SONET path (SPATH), a traffic descriptor (TD) or a virtual ATM interface (VAIF). Once a template is created, a network manager change default parameters within the template to complete particular provisioning tasks. A network manager may also copy a template and modify it to create a new template.

Referring to Fig. 3h, using the interactive interpreter, a network administrator may provision services by selecting (step 888) a template and using the default parameters within that template or copying and renaming (step 889) a particular provisioning template corresponding to a particular provisioning task and either accepting default parameter values provided by the template or changing (step 890) those default values to meet the administrator’s needs. The network administrator may also change parameters and instructions within a copy of a template to create a new template. The modified provisioning templates are sent to or loaded into (step 891) the OSS client, which executes the instructions within the template and issues the appropriate calls (step 892) to the NMS server to satisfy the provisioning need. The OSS client may be written in JAVA and employ script technology. In response to calls received from the OSS client, the NMS server may execute (step 894) the provisioning requests defined by a template immediately or in a “batch-mode” (step 893), perhaps with other calls received from the OSS client or other clients, at a time when network transactions are typically low (e.g., late at night).

Referring to Fig. 3i, at the interactive interpreter prompt 912 (e.g., Enetcli>) a network manager may type in “help” and be provided with a list (e.g., list 913) of commands that are available. In one embodiment, available commands may include bye, close, execute, help, load, manage, open, quit, showCurrent, showTemplate, set, status, writeCurrent, and writeTemplate. Many different commands are possible. The bye command allows

the network manager to exit the interactive interpreter, the close command allows the network manager to close a connection between the OSS client and that NMS server, and the execute command followed by a template type causes the OSS client to execute the instructions within the loaded template corresponding to that template type.

As shown, the help command alone causes the interactive interpreter to display the list of commands. The help command followed by another command provides help information about that command. The load command followed by a template type and a named template loads the named template into the OSS client such that any commands followed by the template type will use the named/loaded template. The manage command followed by an IP address of a network device causes the OSS client to issue a call to an NMS server to establish a connection between the NMS server and that network device. Alternatively, a username and password may also need to be supplied. The open command followed by an NMS server IP address causes the OSS client to open a connection with that NMS server, and again, the network manager may also need to supply a username and password. Instead of an IP address, a domain name server (DNS) name may be provided and a host look up may be used to determine the IP address and access the corresponding device.

The showCurrent command followed by a template type will cause the interactive interpreter to display current parameter values for the loaded template corresponding to that template type. For example, showCurrent SPATH 914 displays a list 915 of parameters and current parameter values for the loaded template corresponding to the SPATH template type. The showTemplate command followed by a template type will cause the OSS client to display available parameters and acceptable parameter values for each parameter within the loaded template. For example, showTemplate SPATH 916 causes the interactive interpreter to display the available parameters 917 within the loaded template corresponding to the SPATH template type. The set command followed by a template type, a parameter name and a value will change the named parameter to the designated value within the loaded template, and a subsequent showCurrent command followed by that template type will show the new parameter value within the loaded.





NMS server will set up a SONET path in the network device using the parameter values passed to the NMS server by the OSS client from the template.

At any time from the Enetcli> prompt, a network manager may change the parameter values within a template. Again, the network manager may use showCurrent followed by a template type to see the current parameter values within the loaded template or showTemplate to see the available parameters within the loaded template. The network manager may then use the set command followed by the template type, parameter name and new parameter value to change a parameter value within the loaded template. For example, after the network manager sets up a SONET path within the network device, the network manager may change one or more parameter values within the loaded SPATH template and re-execute the SPATH template to set up a different SONET path within the same network device.

Once a connection to a network device is open, the network manager may interactively execute any template any number of times to provision services within that network device. The network manager may also create new templates and execute those. The network manager may simply write a new template or use the writeCurrent or writeTemplate commands to copy an existing template into a new template name and then edit the instructions within the new template.

After provisioning services within a first network device, the network manager may open a connection with a second network device to provision services within that second network device. If the NMS server currently connected to the OSS client is capable of establishing a connection with the second network device, then the network manager may simply open a connection to the second network device. If the NMS server currently connected to the OSS client is not capable of establishing a connection with the second network device, then the network manager closes the connections with the NMS server and then opens connections with a second NMS server and the second network device. Thus, a network manager may easily manage / provision services within multiple network devices within multiple networks even if they are managed by different NMS

servers. In addition, other network managers may provision services on the same network devices through the same NMS servers using other OSS clients that are perhaps running on other computer systems. That is, multiple OSS clients may be connected to multiple NMS servers.

Instead of interactively establishing connections with NMS servers and network devices, control templates may be used to non-interactively establish these connections. Referring to Fig. 3k, using a showCurrent command 922 followed by CONTROL causes the interactive interpreter to display parameters available in the loaded CONTROL template. In one embodiment, an execute control command will automatically cause the OSS client to execute instructions within the loaded CONTROL template and open a connection to an NMS server designated within the CONTROL template. Since the OSS client automatically opens a connection with the designated NMS server, the open command may but need not be included within the CONTROL template. In this example, the CONTROL template includes "localhost" 923a as the DNS name of the NMS server with which the OSS client should open a connection. In one embodiment, "localhost" refers to the same system as the OSS client. A username 923b and password 923c may also need to be used to open the connection with the localhost NMS server. The CONTROL template also includes the manage command 923d and a network device IP address 923e of 192.168.9.202. With this information (and perhaps the username and password or another username and password), the OSS client issues calls to the localhost NMS server to cause the server to set up a connection with that network device.

The template may also include an output file name 923f where any output / status information generated in response to the execution of the CONTROL template will be sent. The template may also include a version number 923g. Version numbers allow a new template to be created with the same name as an old template but with a new version number, and the new template may include additional/different parameters and/or instructions. Using version numbers, both old (e.g., not upgraded) and new OSS clients may use the templates but only access those templates having particular version numbers that correspond to the functionality of each OSS client.





SONET path. Many additional provisioning tasks for this network device may be completed in this way.

The BATCH template may then have a task including a set command to modify one or more parameters within a control template to cause the OSS client to set up a connection with a different network device and perhaps a different NMS server. Where the network manager wishes to provision a network device capable of being connected to through the currently connected NMS server, for example, localhost, then the BATCH template need only have task61 925e including “set CONTROL System” followed by the IP address of the different network device, for example, 192.168.9.201. The BATCH template then has a task62 925f including “execute CONTROL”, which causes the OSS client to issue calls to the localhost NMS server to establish a connection with the different network device. The BATCH template may then have tasks including execute commands followed by provisioning templates, for example, task63 925g including “execute SPATH”, to provision services within the different network device.

If the network manager wishes to provision a network device coupled with another NMS server, then the BATCH template includes, for example, task108 925h including “close” to drop the connection between the OSS client and localhost NMS server. The BATCH template may then have, for example, task109 925i including “set CONTROL Server Server1” to change the server parameter within the loaded CONTROL template to Server1 and task110 925j including “set CONTROL System 192.168.8.200” to change the network device parameter within the loaded CONTROL template to the IP address of the new network device. The BATCH template may then have task111 925k including “execute CONTROL” to cause the OSS client to set up connections to the Server1 NMS server and to network device 192.168.8.200. The BATCH template may then include tasks with execute commands followed by provisioning template types to provision services within the network device, for example, task112 925L includes “execute SPATH”.

The templates and interactive interpreter / OSS client may be loaded and executed on a central OSS computer system(s) and used to provision services in one or more network devices in one or more network domains. A network administrator may install an OSS client at various locations and/or for “manage anywhere” purposes, web technology may be used to allow a network manager to download an OSS client program from a web accessible server onto a computer at any location. The network manager may then use the OSS client in the same manner as when it is loaded onto a central OSS computer system. Thus, the network manager may provision services from any computer at any location.

Provisioning templates may be written to apply to different types of network devices. The network administrator does not need to know details of the network device being provisioned as the parameters required and available for modification are listed in the various templates. Consequently, the templates allow for multifaceted integration of different network management systems (NMS) into existing OSS infrastructures.

Instead of using template executable files and an OSS client, network managers may prefer to use their standard OSS interface to provision services in various network devices. In one embodiment, therefore, a single OSS client application programming interface (API) and a library of compiled code may be linked directly into the OSS software. The library of compiled code is a subset of the compiled code used to create the OSS client, with built-in templates including provisioning, control, batch and other types of templates. The OSS software then uses the supported templates as documentation of the necessary parameters needed for each provisioning task and presents template streams (null terminated arrays of arguments that serialize the totality of arguments required to construct a supported template) via the single API for potential alteration through the OSS standard interface. Since the network managers are comfortable working with the OSS interface, provisioning services may be made more efficient and simple by directly linking the OSS client API and templates into the OSS software.

Typically, OSS software is written in C or C++ programming language. In one embodiment, the OSS client and templates are written in JAVA, and JAVA Native Interface (JNI) is used by the OSS software to access the JAVA OSS client API and templates.

#### Inter-Process Communication:

As described above, the operating system assigns a unique process identification number (proc\_id) to each spawned process. Each process has a name, and each process knows the names of other processes with which it needs to communicate. The operating system keeps a list of process names and the assigned process identification numbers. Processes send messages to other processes using the assigned process identification numbers without regard to what board is executing each process (i.e., process location).

Application Programming Interfaces (APIs) define the format and type of information included in the messages.

The modular software architecture configuration model requires a single software process to support multiple configurable objects. For example, as described above, an ATM application may support configurations requiring multiple ATM interfaces and thousands of permanent virtual connections per ATM interface. The number of processes and configurable objects in a modular software architecture can quickly grow especially in a distributed processing system. If the operating system assigns a new process for each configurable object, the operating system's capabilities may be quickly exceeded.

For example, the operating system may be unable to assign a process for each ATM interface, each service endpoint, each permanent virtual circuit, etc.. In some instances, the process identification numbering scheme itself may not be large enough. Where protected memory is supported, the system may have insufficient memory to assign each process and configurable object a separate memory block. In addition, supporting a large number of independent processes may reduce the operating system's efficiency and slow the operation of the entire computer system.







Referring to Fig. 16c, when the SEM, for example, SEM 96a, notifies a device driver, for example, device driver (DD) 222, of its assigned SE number, DD 222 uses the SE number to generate a device driver name. In the continuing example from above, where the ATM over SONET protocol is to be delivered to port 44a and DD 222, the device driver name may be for example, atm.se1. DD 222 publishes this name to NS 220b along with the process identification assigned by the operating system and the name of its service endpoints.

Applications, for example, ATM 224, also use SE numbers to generate the names of device drivers with which they need to communicate and subscribe to NS 220b for those device driver names, for example, atm.se1. If the device driver has published its name and process identification with NS 220b, then NS 220b notifies ATM 224 of the process identification number associated with atm.se1 and the name of its service endpoints. ATM 224 can then use the process identification to communicate with DD 222 and, hence, any objects within DD 222. If device driver 222 is restarted or upgraded, SEM 96a will again notify DD 222 that its associated service endpoint is SE 1 which will cause DD 222 to generate the same name of atm.se1. DD 222 will then re-publish with NS 220b and include the newly assigned process identification number. NS 220b will provide the new process identification number to ATM 224 to allow the processes to continue to communicate. Similarly, if ATM 224 is restarted or upgraded, it will use the service endpoint numbers from ATM interface table 114 and, as a result, derive the same name of atm.se1 for DD 222. ATM 224 will then re-subscribe with NS 220b.

Computer system 10 includes a distributed name server (NS) application including a name server process 220a-220n on each board (central processor and line card). Each name server process handles the registration and subscription for the processes on its corresponding board. For distributed applications, after each application (e.g., ATM 224a-224n) registers with its local name server (e.g., 220b-220n), the name server registers the application with each of the other name servers. In this way, only distributed applications are registered / subscribed system wide which avoids wasting system resources by registering local processes system wide.

The operating system, through the use of assigned process identification numbers, allows for inter-process communication (IPC) regardless of the location of the processes within the computer system. The flexible naming process allows applications to use data in the configuration database to determine the names of other applications and configurable objects, thus, alleviating the need for hard coded process names. The name server notifies individual processes of the existence of the processes and objects with which they need to communicate and the process identification numbers needed for that communication. The termination, re-start or upgrade of an object or process is, therefore, transparent to other processes, with the exception of being notified of new process identification numbers. For example, due to a configuration change initiated by the user of the computer system, service endpoint 253 (Fig. 16b), may be terminated within device driver 248 and started instead within device driver 250. This movement of the location of object 253 is transparent to both ATM 240 and 241. Name server 264 simply notifies whichever processes have subscribed for SE 253 of the newly assigned process identification number corresponding to device driver 250.

The name server or a separate binding object manager (BOM) process may allow processes and configurable objects to pass additional information adding further flexibility to inter-process communications. For example, flexibility may be added to the application programming interfaces (APIs) used between processes. As discussed above, once a process is given a process identification number by the name server corresponding to an object with which it needs to communicate, the process can then send messages to the other process in accordance with a predefined application programming interface (API). Instead of having a predefined API, the API could have variables defined by data passed through the name server or BOM, and instead of having a single API, multiple APIs may be available and the selection of the API may be dependent upon information passed by the name server or BOM to the subscribed application.

Referring to Fig. 16d, a typical API will have a predefined message format 270 including, for example, a message type 272 and a value 274 of a fixed number of bits (e.g., 32).



compatible by supporting older configurable objects, for example, old ATM interfaces. Backward compatibility has been provided in the past through revision numbers, however, initial communication between processes involved polling to determine version numbers and where multiple applications need to communicate, each would need to poll the other. The name server / BOM eliminates the need for polling.

As described above, the name server notifies subscriber applications each time a subscribed for process is terminated. Instead, the name server / BOM may not send such a notification unless the System Resiliency Manager (SRM) tells the name server / BOM to send such a notification. For example, depending upon the fault policy / resiliency of the system, a particular software fault may simply require that a process be restarted. In such a situation, the name server / BOM may not notify subscriber applications of the termination of the failed process and instead simply notify the subscriber applications of the newly assigned process identification number after the failed process has been restarted. Data that is sent by the subscriber processes after the termination of the failed process and prior to the notification of the new process identification number may be lost but the recovery of this data (if any) may be less problematic than notifying the subscriber processes of the failure and having them hold all transmissions. For other faults, or after a particular software fault occurs a predetermined number of times, the SRM may then require the name server / BOM to notify all subscriber processes of the termination of the failed process. Alternatively, if a terminated process does not re-register within a predetermined amount of time, the name server / BOM may then notify all subscriber processes of the termination of the failed process.

#### Configuration Change:

Over time the user will likely make hardware changes to the computer system that require configuration changes. For example, the user may plug a fiber or cable (i.e., network connection) into an as yet unused port, in which case, the port must be enabled and, if not already enabled, then the port's line card must also be enabled. As other examples, the user may add another path to an already enabled port that was not fully utilized, and the user may add another line card to the computer system. Many types of configuration

changes are possible, and the modular software architecture allows them to be made while the computer system is running (hot changes). Configuration changes may be automatically copied to persistent storage as they are made so that if the computer system is shut down and rebooted, the memory and configuration database will reflect the last known state of the hardware.

To make a configuration change, the user informs the NMS (e.g., NMS client 850a, Fig. 2a) of the particular change, and similar to the process for initial configuration, the NMS (e.g., NMS server 851a, Fig. 2a) changes the appropriate tables in the configuration database (copied to the NMS database) to implement the change.

Referring to Fig. 17, in one example of a configuration change, the user notifies the NMS that an additional path will be carried by SONET fiber 70c connected to port 44c. A new service endpoint (SE) 164 and a new ATM interface 166 are needed to handle the new path. The NMS adds a new record (row 168, Fig. 10) to service endpoint table (SET) 76 to include service endpoint 10 corresponding to port physical identification number (PID) 1502 (port 44c). The NMS also adds a new record (row 170, Fig. 13) to ATM instance table 114 to include ATM interface (IF) 12 corresponding to ATM group 3 and SE 10. Configuration database 42 may automatically copy the changes made to SET 76 and ATM instance table 114 to persistent storage 21 such that if the computer system is shut down and rebooted, the changes to the configuration database will be maintained.

Configuration database 42 also notifies (through the active query process) SEM 96c that a new service endpoint (SE 10) was added to the SET corresponding to its port (PID 1502), and configuration database 42 also notifies ATM instantiation 112 that a new ATM interface (ATM-IF 166) was added to the ATM interface table corresponding to ATM group 3. ATM 112 establishes ATM interface 166 and SEM 96c notifies port driver 142 that it has been assigned SE10. A communication link is established through NS 220b. Device driver 142 generates a service endpoint name using the assigned SE number and publishes this name and its process identification number with NS 220b. ATM interface 166 generates the same service endpoint name and subscribes to NS 220b

for that service endpoint name. NS 220b provides ATM interface 166 with the process identification assigned to DD 142 allowing ATM interface 166 to communicate with device driver 142.

Certain board changes to computer system 10 are also configuration changes. After power-up and configuration, a user may plug another board into an empty computer system slot or remove an enabled board and replace it with a different board. In the case where applications and drivers for a line card added to computer system 10 are already loaded, the configuration change is similar to initial configuration. The additional line card may be identical to an already enabled line card, for example, line card 16a or if the additional line card requires different drivers (for different components) or different applications (e.g., IP), the different drivers and applications are already loaded because computer system 10 expects such cards to be inserted.

Referring to Fig. 18, while computer system 10 is running, when another line card 168 is inserted, master MCD 38 detects the insertion and communicates with a diagnostic program 170 being executed by the line card's processor 172 to learn the card's type and version number. MCD 38 uses the information it retrieves to update card table 47 and port table 49. MCD 38 then searches physical module description (PMD) file 48 in memory 40 for a record that matches the retrieved card type and version number and retrieves the name of the mission kernel image executable file (MKI.exe) that needs to be loaded on line card 168. Once determined, master MCD 38 passes the name of the MKI executable file to master SRM 36. SRM 36 downloads MKI executable file 174 from persistent storage 21 and passes it to a slave SRM 176 running on line card 168. The slave SRM executes the received MKI executable file.

Referring to Fig. 19, slave MCD 178 then searches PMD file 48 in memory 40 on central processor 12 for a match with its line card's type and version number to find the names of all the device driver executable files associated needed by its line card. Slave MCD 178 provides these names to slave SRM 176 which then downloads and executes the device driver executable files (DD.exe) 180 from memory 40.



When master MCD 38 updates card table 47, configuration database 42 updated NMS database 61 which sends NMS 60 (e.g., NMS Server 851a, Fig. 2a) a notification of the change including card type and version number, the slot number into which the card was inserted and the physical identification (PID) assigned to the card by the master MCD. The NMS is updated, assigns an LID and updates the logical to physical table and notifies the user of the new hardware. The user then tells the NMS how to configure the new hardware, and the NMS implements the configuration change as described above for initial configuration.

#### Logical Model Change:

Where applications and device drivers for a new line card are not already loaded and where changes or upgrades to already loaded applications and device drivers are needed, logical model 280 (Figs. 2a-3e) must be changed and new view ids and APIs, NMS JAVA interface files, persistent layer metadata files and new DDL files must be re-generated. Software model 286 is changed to include models of the new or upgraded software, and hardware model 284 is changed to include models of any new hardware. New logical model 280' is then used by code generation system 336 to re-generate view ids and APIs for each application, including any new applications, for example, ATM version two 360, or device drivers, for example, device driver 362, and to re-generate DDL files 344' and 348' including new SQL commands and data relevant to the new hardware and/or software. The new logical model is also used to generate new NMS JAVA interface files 347' and new persistent layer metadata files 349'. Each application, including any new applications or drivers, is then pulled into the build process and links in a corresponding view id and API. The new applications and/or device drivers, NMS JAVA interface files, new persistent layer metadata files and the new DDL files as well as any new hardware are then sent to the user of computer system 10.

New and upgraded applications and device drivers are being used by way of an example, and it should be understood that other processes, for example, modular system services

and new Mission Kernel Images (MKIs), may be changed or upgraded in the same fashion.

Referring to Fig. 20, the user instructs the NMS to download the new applications and/or device drivers, for example, ATM version two 360 and device driver 362, as well as the new DDL files, for example, DDL files 344' and 348', into memory on work station 62. The NMS uses new NMS database DDL file 348' to upgrade NMS database 61 into new NMS database 61'. Alternatively, a new NMS database may be created using DDL file 348' and both databases temporarily maintained.

#### Application Upgrade:

For new applications and application upgrades, the NMS works with a software management system (SMS) service to implement the change while the computer system is running (hot upgrades or additions). The SMS is one of the modular system services, and like the MCD and the SRM, the SMS is a distributed application. Referring to Fig. 20, a master SMS 184 is executed by central processor 12 while slave SMSs 186a-186n are executed on each board.

Upgrading a distributed application that is running on multiple boards is more complicated than upgrading an application running on only one board. As an example of a distributed application upgrade, the user may want to upgrade all ATM applications running on various boards in the system using new ATM version two 360. This is by way of example, and it should be understood, that only one ATM application may be upgraded so long as it is compatible with the other versions of ATM running on other boards. ATM version two 360 may include many sub-processes, for example, an upgraded ATM application executable file (ATMv2.exe 189), an upgraded ATM control executable file (ATMv2\_cntrl.exe 190) and an ATM configuration control file (ATMv2\_cnfg\_cntrl.exe). The NMS downloads ATMv2.exe 189, ATMv2\_cntrl.exe and ATMv2\_cnfg\_cntrl.exe to memory 40 on central processor 12.



42' by creating new tables, for example, ATM group table 108' and ATM interface table 114'.

Existing processes using their view ids and APIs to access new configuration database 42' in the same manner as they accessed old configuration database 42. However, when new processes (e.g., ATM version two 360 and device driver 362) access new configuration database 42', their view ids and APIs allow them to access new tables and data within new configuration database 42'.

The master SMS also reads ATM group table 108' to determine that instances of ATM are being executed on line cards 16a-16n. In order to upgrade a distributed application, in this instance, ATM, the Master SMS will use a lock step procedure. Master SMS 184 tells each slave SMS 186b-186n to stall the current versions of ATM. When each slave responds, Master SMS 184 then tells slave SMSs 186b-186n to download and execute ATMv2\_cntrl.exe 190 from memory 40. Upon instructions from the slave SMSs, slave SRMs 37b-37n download and execute copies of ATMv2\_cntrl.exe 204a-204n. The slave SMSs also pass data to the ATMv2cntrl.exe file through the SRM. The data instructs the control shim to start in upgrade mode and passes required configuration information. The upgraded ATMv2 controllers 204a-204n then use ATM group table 108' and ATM interface table 114' as described above to implement ATMv2 206a-206n on each of the line cards. In this example, each ATM controller is shown implementing one instance of ATM on each line card, but as explained below, the ATM controller may implement multiple instances of ATM on each line card.

As part of the upgrade mode, the updated versions of ATMv2 206a-206n retrieve active state from the current versions of ATM 188a-188n. The retrieval of active state can be accomplished in the same manner that a redundant or backup instantiation of ATM retrieves active state from the primary instantiation of ATM. When the upgraded instances of ATMv2 are executing and updated with active state, the ATMv2 controllers notify the slave SMSs 186b-186n on their board and each slave SMS 186b-186n notifies master SMS 184. When all boards have notified the master SMS, the master SMS tells

the slave SMSs to switchover to ATMv2 206a-206n. The slave SMSs tell the slave SRMs running on their board, and the slave SRMs transition the new ATMv2 processes to the primary role. This is termed “lock step upgrade” because each of the line cards is switched over to the new ATMv2 processes simultaneously.

There may be upgrades that require changes to multiple applications and to the APIs for those applications. For example, a new feature may be added to ATM that also requires additional functionality to be added to the Multi-Protocol Label Switching (MPLS) application. The additionally functionality may change the peer-to-peer API for ATM, the peer-to-peer API for MPLS and the API between ATM and MPLS. In this scenario, the upgrade operation must avoid allowing the “new” version of ATM to communicate with itself or the “old” version of MPLS and vice versa. The master SMS will use the release number scheme to determine the requirements for the individual upgrade. For example, the upgrade may be from release 1.0.0.0 to 1.0.1.3 where the release differs by the subsystem compatibility level. The SMS implements the upgrade in a lock step fashion. All instances of ATM and MPLS are upgraded first. The slave SMS on each line card then directs the slave SRM on its board to terminate all “old” instances of ATM and MPLS and switchover to the new instances of MPLS and ATM. The simultaneous switchover to new versions of both MPLS and ATM eliminate any API compatibility errors.

Referring to Fig. 22, instead of directly upgrading configuration database 42 on central processor 12, a backup configuration database 420 on a backup central processor 13 may be upgraded first. As described above, computer system 10 includes central processor 12. Computer system 10 may also include a redundant or backup central processor 13 that mirrors or replicates the active state of central processor 12. Backup central processor 13 is generally in stand-by mode unless central processor 12 fails at which point a fail-over to backup central processor 13 is initiated to allow the backup central processor to be substituted for central processor 12. In addition to failures, backup central processor 13 may be used for software and hardware upgrades that require changes to the configuration database. Through backup central processor 13, upgrades

can be made to backup configuration database 420 instead of to configuration database 42.

The upgrade is begun as discussed above with the NMS downloading ATM version two 360 – including ATMv2.exe 189, ATMv2\_cntrl.exe and ATMv2\_cnfg\_cntrl.exe – and DDL file 344' to memory on central processor 12. Simultaneously, because central processor 13 is in backup mode, the application and DDL file are also copied to memory on central processor 13. The NMS also creates a software load record in SMS table 192, 192' indicating the upgrade. In this embodiment, when the SMS determines that the scope of the upgrade requires an upgrade to the configuration database, the master SMS instructs slave SMS 186e on central processor 13 to perform the upgrade. Slave SMS 186e works with slave SRM 37e to cause backup processor 13 to change from backup mode to upgrade mode.

In upgrade mode, backup processor 13 stops replicating the active state of central processor 12. Any changes made to new configuration database 420 are copied to new NMS database 61'. Slave SMS 186e then directs slave SRM 37e to execute the configuration control file which uses DDL file 344' to upgrade configuration database 420.

Once configuration database 420 is upgraded, a fail-over or switch-over from central processor 12 to backup central processor 13 is initiated. Central processor 13 then begins acting as the primary central processor and applications running on central processor 13 and other boards throughout computer system 10 begin using upgraded configuration database 420.

Central processor 12 may not become the backup central processor right away. Instead, central processor 12 with its older copy of configuration database 42 stays dormant in case an automatic downgrade is necessary (described below). If the upgrade goes smoothly and is committed (described below), then central processor 12 will begin

operating in backup mode and replace old configuration database 42 with new configuration database 420.

#### Device Driver Upgrade:

Device driver software may also be upgraded and the implementation of device driver upgrades is similar to the implementation of application upgrades. The user informs the NMS of the device driver change and provides a copy of the new software (e.g., DD^.exe 362, Figs. 20 and 23). The NMS downloads the new device driver to memory 40 on central processor 12, and the NMS writes a new record in SMS table 192 indicating the device driver upgrade. Configuration database 42 sends a notification to master SMS 184 including the name of the driver to be upgraded. To determine where the original device driver is currently running in computer system 10, the master SMS searches PMD file 48 for a match of the device driver name (existing device driver, not upgraded device driver) to learn with which module type and version number the device driver is associated. The device driver may be running on one or more boards in computer system 10. As described above, the PMD file corresponds the module type and version number of a board with the mission kernel image for that board as well as the device drivers for that board. The SMS then searches card table 47 for a match with the module type and version number found in the PMD file. Card table 47 includes records corresponding module type and version number with the physical identification (PID) and slot number of that board. The master SMS now knows the board or boards within computer system 10 on which to load the upgraded device driver. If the device driver is for a particular port, then the SMS must also search the port table to learn the PID for that port.

The master SMS notifies each slave SMS running on boards to be upgraded of the name of the device driver executable file to download and execute. In the example, master SMS 184 sends slave SMS 186f the name of the upgraded device driver (DD^.exe 362) to download. Slave SMS 186f tells slave SRM to download and execute DD^.exe 362 in upgrade mode. Once downloaded, DD^.exe 363 (copy of DD^.exe 362) gathers active state information from the currently running DD.exe 212 in a similar fashion as a redundant or backup device driver would gather active state. DD^.exe 362 then notifies

slave SRM 37f that active state has been gathered, and slave SRM 37f stops the current DD.exe 212 process and transitions the upgraded DD^.exe 362 process to the primary role.

#### Automatic Downgrade:

Often, implementation of an upgrade, can cause unexpected errors in the upgraded software, in other applications or in hardware. As described above, a new configuration database 42' (Fig. 20) is generated and changes to the new configuration database are made in new tables (e.g., ATM interface table 114' and ATM group table 108', Fig. 20) and new executable files (e.g., ATMv2.exe 189, ATMv2\_cntrl.exe 190 and ATMv2\_cnfg\_cntrl.exe 191) are downloaded to memory 40. Importantly, the old configuration database records and the original application files are not deleted or altered. In the embodiment where changes are made directly to configuration database 42 on central processor 12, they are made only in non-persistent memory until committed (described below). In the embodiment where changes are made to backup configuration database 420 on backup central processor 13, original configuration database 42 remains unchanged.

Because the operating system provides a protected memory model that assigns different process blocks to different processes, including upgraded applications, the original applications will not share memory space with the upgraded applications and, therefore, cannot corrupt or change the memory used by the original application. Similarly, memory 40 is capable of simultaneously maintaining the original and upgraded versions of the configuration database records and executable files as well as the original and upgraded versions of the applications (e.g., ATM 188a-188n). As a result, the SMS is capable of an automatic downgrade on the detection of an error. To allow for automatic downgrade, the SRMs pass error information to the SMS. The SMS may cause the system to revert to the old configuration and application (i.e., automatic downgrade) on any error or only for particular errors.



As mentioned, often upgrades to one application may cause unexpected faults or errors in other software. If the problem causes a system shut down and the configuration upgrade was stored in persistent storage, then the system, when powered back up, will experience the error again and shut down again. Since, the upgrade changes to the configuration database are not copied to persistent storage 21 until the upgrade is committed, if the computer system is shut down, when it is powered back up, it will use the original version of the configuration database and the original executable files, that is, the computer system will experience an automatic downgrade.

Additionally, a fault induced by an upgrade may cause the system to hang, that is, the computer system will not shut down but will also become inaccessible by the NMS and inoperable. To address this concern, in one embodiment, the NMS and the master SMS periodically send messages to each other indicating they are executing appropriately. If the SMS does not receive one of these messages in a predetermined period of time, then the SMS knows the system has hung. The master SMS may then tell the slave SMSs to revert to the old configuration (i.e., previously executing copies of ATM 188a-188n) and if that does not work, the master SMS may re-start / re-boot computer system 10. Again, because the configuration changes were not saved in persistent storage, when the computer system powers back up, the old configuration will be the one implemented.

#### Evaluation Mode:

Instead of implementing a change to a distributed application across the entire computer system, an evaluation mode allows the SMS to implement the change in only a portion of the computer system. If the evaluation mode is successful, then the SMS may fully implement the change system wide. If the evaluation mode is unsuccessful, then service interruption is limited to only that portion of the computer system on which the upgrade was deployed. In the above example, instead of executing the upgraded ATMv2 189 on each of the line cards, the ATMv2 configuration convert file 191 will create an ATMv2 group table 108' indicating an upgrade only to one line card, for example, line card 16a. Moreover, if multiple instantiations of ATM are running on line card 16a (e.g., one instantiation per port), the ATMv2 configuration convert file may indicate through

ATMv2 interface table 114' that the upgrade is for only one instantiation (e.g., one port) on line card 16a. Consequently, a failure is likely to only disrupt service on that one port, and again, the SMS can further minimize the disruption by automatically downgrading the configuration of that port on the detection of an error. If no error is detected during the evaluation mode, then the upgrade can be implemented over the entire computer system.

#### Upgrade Commitment:

Upgrades are made permanent by saving the new application software and new configuration database and DDL file in persistent storage and removing the old configuration data from memory 40 as well as persistent storage. As mentioned above, changes may be automatically saved in persistent storage as they are made in non-persistent memory (no automatic downgrade), or the user may choose to automatically commit an upgrade after a successful time interval lapses (evaluation mode). The time interval from upgrade to commitment may be significant. During this time, configuration changes may be made to the system. Since these changes are typically made in non-persistent memory, they will be lost if the system is rebooted prior to upgrade commitment. Instead, to maintain the changes, the user may request that certain configuration changes made prior to upgrade commitment be copied into the old configuration database in persistent memory. Alternatively, the user may choose to manually commit the upgrade at his or her leisure. In the manual mode, the user would ask the NMS to commit the upgrade and the NMS would inform the master SMS, for example, through a record in the SMS table.

#### Independent Process Failure and Restart:

Depending upon the fault policy managed by the slave SRMs on each board, the failure of an application or device driver may not immediately cause an automatic downgrade during an upgrade process. Similarly, the failure of an application or device driver during normal operation may not immediately cause the fail over to a backup or redundant board. Instead, the slave SRM running on the board may simply restart the failing

process. After multiple failures by the same process, the fault policy may cause the SRM to take more aggressive measures such as automatic downgrade or fail-over.

Referring to Fig. 24, if an application, for example, ATM application 230 fails, the slave SRM on the same board as ATM 230 may simply restart it without having to reboot the entire system. As described above, under the protected memory model, a failing process cannot corrupt the memory blocks used by other processes. Typically, an application and its corresponding device drivers would be part of the same memory block or even part of the same software program, such that if the application failed, both the application and device drivers would need to be restarted. Under the modular software architecture, however, applications, for example ATM application 230, are independent of the device drivers, for example, ATM driver 232 and Device Drivers (DD) 234a-234c. This separation of the data plane (device drivers) and control plane (applications) results in the device drivers being peers of the applications. Hence, while the ATM application is terminated and restarted, the device drivers continue to function.

For network devices, this separation of the control plane and data plane means that the connections previously established by the ATM application are not lost when ATM fails and hardware controlled by the device drivers continue to pass data through connections previously established by the ATM application. Until the ATM application is restarted and re-synchronized (e.g., through an audit process, described below) with the active state of the device drivers, no new network connections may be established but the device drivers continue to pass data through the previously established connections to allow the network device to minimize disruption and maintain high availability.

#### Local Backup:

If a device driver, for example, device driver 234, fails instead of an application, for example, ATM 230, then data cannot be passed. For a network device, it is critical to continue to pass data and not lose network connections. Hence, the failed device driver must be brought back up (i.e., recovered) as soon as possible. In addition, the failing device driver may have corrupted the hardware it controls, therefore, that hardware must



Local backup 236 stores the last snap shot of critical state information used by the original device driver before it failed. The data in local backup 236 is in the format required by the device driver. In the case of a network device, local back up data may include path information, for example, service endpoint, path width and path location. Local back up data may also include virtual interface information, for example, which virtual interfaces were configured on which paths and virtual circuit (VC) information, for example, whether each VC is switched or passed through segmentation and reassembly (SAR), whether each VC is a virtual channel or virtual path and whether each VC is multicast or merge. The data may also include traffic parameters for each VC, for example, service class, bandwidth and/or delay requirements.

Using the data in the local backup allows the device driver to quickly recover. An Audit process resynchronizes the restarted device driver with associated applications and other device drivers such that the data plane can again transfer network data. Having the backup be local reduces recovery time. Alternatively, the backup could be stored remotely on another board but the recovery time would be increased by the amount of time required to download the information from the remote location.

#### Audit Process:

It is virtually impossible to ensure that a failed process is synchronized with other processes when it restarts, even when backup data is available. For example, an ATM application may have set up or torn down a connection with a device driver but the device driver failed before it updated corresponding backup data. When the device driver is restarted, it will have a different list of established connections than the corresponding ATM application (i.e., out of synchronization). The audit process allows processes like device drivers and ATM applications to compare information, for example, connection tables, and resolve differences. For instance, connections included in the driver's connection table and not in the ATM connection table were likely torn down by ATM prior to the device driver crash and are, therefore, deleted from the device driver connection table. Connections that exist in the ATM connection table and not in the device driver connection table were likely set up prior to the device driver failure and

may be copied into the device driver connection table or deleted from the ATM connection table and re-set up later. If an ATM application fails and is restarted, it must execute an audit procedure with its corresponding device driver or drivers as well as with other ATM applications since this is a distributed application.

#### Vertical Fault Isolation:

Typically, a single instance of an application executes on a single card or in a system. Fault isolation, therefore, occurs at the card level or the system level, and if a fault occurs, an entire card – and all the ports on that card – or the entire system – and all the ports in the system -- is affected. In a large communications platform, thousands of customers may experience service outages due to a single process failure.

For resiliency and fault isolation one or more instances of an application and/or device driver may be started per port on each line card. Multiple instances of applications and device drivers are more difficult to manage and require more processor cycles than a single instance of each but if an application or device driver fails, only the port those processes are associated with is affected. Other applications and associated ports – as well as the customers serviced by those ports -- will not experience service outages. Similarly, a hardware failure associated with only one port will only affect the processes associated with that port. This is referred to as vertical fault isolation.

Referring to Fig. 25, as one example, line card 16a is shown to include four vertical stacks 400, 402, 404, and 406. Vertical stack 400 includes one instance of ATM 110 and one device driver 43a and is associated with port 44a. Similarly, vertical stacks 402, 404 and 406 include one instance of ATM 111, 112, 113 and one device driver 43b, 43c, 43d, respectively and each vertical stack is associated with a separate port 44b, 44c, 44d, respectively. If ATM 112 fails, then only vertical stack 404 and its associated port 44c are affected. Service is not disrupted on the other ports (ports 44a, 44b, 44d) since vertical stacks 400, 402, and 406 are unaffected and the applications and drivers within those stacks continue to execute and transmit data. Similarly, if device driver 43b fails, then only vertical stack 402 and its associated port 44b are affected.

Vertical fault isolation allows processes to be deployed in a fashion supportive of the underlying hardware architecture and allows processes associated with particular hardware (e.g., a port) to be isolated from processes associated with other hardware (e.g., other ports) on the same or a different line card. Any single hardware or software failure will affect only those customers serviced by the same vertical stack. Vertical fault isolation provides a fine grain of fault isolation and containment. In addition, recovery time is reduced to only the time required to re-start a particular application or driver instead of the time required to re-start all the processes associated with a line card or the entire system.

#### Fault / Event Detection:

Traditionally, fault detection and monitoring does not receive a great deal of attention from network equipment designers. Hardware components are subjected to a suite of diagnostic tests when the system powers up. After that, the only way to detect a hardware failure is to watch for a red light on a board or wait for a software component to fail when it attempts to use the faulty hardware. Software monitoring is also reactive. When a program fails, the operating system usually detects the failure and records minimal debug information.

Current methods provide only sporadic coverage for a narrow set of hard faults. Many subtler failures and events often go undetected. For example, hardware components sometimes suffer a minor deterioration in functionality, and changing network conditions stress the software in ways that were never expected by the designers. At times, the software may be equipped with the appropriate instrumentation to detect these problems before they become hard failures, but even then, network operators are responsible for manually detecting and repairing the conditions.

Systems with high availability goals must adopt a more proactive approach to fault and event monitoring. In order to provide comprehensive fault and event detection, different hierarchical levels of fault/event management software are provided that intelligently









the slave SRM may escalate the failure to the next hierarchical scope by notifying master SRM 36 of the failure. Alternatively, the master SRM may use its fault history for a particular line card to determine when a threshold is exceeded and automatically execute its fault policy.

When master SRM 36 detects or receives notice of a failure or event, it notifies slave logging entity 433a, which notifies master logging entity 431. The master logging entity 431 may log the failure or event in master log file 435 and the slave logging entity may log the failure or event in local event log 435a. Master SRM 36 also determines the appropriate corrective action based on the type of failure or event and its fault policy. Corrective action may require failing-over one or more line cards 16a-16n or other boards, including central processor 12, to redundant backup boards or, where backup boards are not available, simply shutting particular boards down. Some failures may require the master SRM to re-boot the entire computer system.

An example of a common error is a memory access error. As described above, when the slave SRM starts a newinstance of an application, it requests a protected memory block from the local operating system. The local operating systems assign each instance of an application one block of local memory and then program the local memory management unit (MMU) hardware with which processes have access (read and/or write) to each block of memory. An MMU detects a memory access error when a process attempts to access a memory block not assigned to that process. This type of error may result when the process generates an invalid memory pointer. The MMU prevents the failing process from corrupting memory blocks used by other processes (i.e., protected memory model) and sends a hardware exception to the local processor. A local operating system fault handler detects the hardware exception and determines which process attempted the invalid memory access. The fault handler then notifies the local slave SRM of the hardware exception and the process that caused it. The slave SRM determines the application instance within which the fault occurred and then goes through the process described above to determine whether to take corrective action, such as restarting the application, or escalate the fault to the master SRM.

As another example, a device driver, for example, device driver 43a may determine that the hardware associated with its port, for example, port 44a, is in a bad state. Since the failure may require the hardware to be swapped out or failed-over to redundant hardware or the device driver itself to be re-started, the device driver notifies slave SRM 37b. The slave SRM then goes through the process described above to determine whether to take corrective action or escalate the fault to the master SRM.

As a third example, if a particular application instance repeatedly experiences the same software error but other similar application instances running on different ports do not experience the same error, the slave SRM may determine that it is likely a hardware error. The slave SRM would then notify the master SRM which may initiate a fail-over to a backup board or, if no backup board exists, simply shut down that board or only the failing port on that board. Similarly, if the master SRM receives failure reports from multiple boards indicating Ethernet failures, the master SRM may determine that the Ethernet hardware is the problem and initiate a fail-over to backup Ethernet hardware.

Consequently, the failure type and the failure policy determine at what scope recovery action will be taken. The higher the scope of the recovery action, the larger the temporary loss of services. Speed of recovery is one of the primary considerations when establishing a fault policy. Restarting a single software process is much faster than switching over an entire board to a redundant board or re-booting the entire computer system. When a single process is restarted, only a fraction of a card's services are affected. Allowing failures to be handled at appropriate hierarchical levels avoids unnecessary recovery actions while ensuring that sufficient recovery actions are taken, both of which minimize service disruption to customers.

#### Hierarchical Descriptors:

Hierarchical descriptors may be used to provide information specific to each failure or event. The hierarchical descriptors provide granularity with which to report faults, take action based on fault history and apply fault recovery policies. The descriptors can be





allows users to perform manual overrides to suit their specific requirements and to tailor their policies based on the individual failure scenarios that they are experiencing.

The modification may cause the hierarchical scope to react more or less aggressively to particular known faults or events, and the modification may add recovery actions to handle newly learned faults or events. The modification may also provide a temporary patch while a software or hardware upgrade is developed to fix a particular error.

If an application runs out of memory space, it notifies the operating system and asks for more memory. For certain applications, this is standard operating procedure. As an example, an ATM application may have set up a large number of virtual circuits and to continue setting up more, additional memory is needed. For other applications, a request for more memory indicates a memory leak error. The fault policy may require that the application be re-started causing some service disruption. It may be that re-starting the application eventually leads to the same error due to a bug in the software. In this instance, while a software upgrade to fix the bug is developed, a temporary patch to the fault policy may be necessary to allow the memory leak to continue and prevent repeated application re-starts that may escalate to line card re-start or fail-over and eventually to a re-boot of the entire computer system. A temporary patch to the default fault policy may simply allow the hierarchical scope, for example, the local resiliency manager or the slave SRM, to assign additional memory to the application. Of course, an eventual re-start of the application is likely to be required if the application's leak consumes too much memory.

A temporary patch may also be needed while a hardware upgrade or fix is developed for a particular hardware fault. For instance, under the default fault policy, when a particular hardware fault occurs, the recovery policy may be to fail-over to a backup board. If the backup board includes the same hardware with the same hardware bug, for example, a particular semiconductor chip, then the same error will occur on the backup board. To prevent a repetitive fail-over while a hardware fix is developed, the temporary patch to the default fault policy may be to restart the device driver associated with the particular hardware instead of failing-over to the backup board.

In addition to the above needs, a configurable fault policy also allows purchasers of computer system 10 (e.g., network service providers) to define their own policies. For example, a network service provider may have a high priority customer on a particular port and may want all errors and events (even minor ones) to be reported to the NMS and displayed to the network manager. Watching all errors and events might give the network manager early notice of growing resource consumption and the need to plan to dedicate additional resources to this customer.

As another example, a user of computer system 10 may want to be notified when any process requests more memory. This may give the user early notice of the need to add more memory to their system or to move some customers to different line cards.

Referring again to Fig. 26, to change the default fault policy as defined by default fault policy (DFP) files 430a-430n, a configuration fault policy file 429 is created by the NMS in the configuration database. An active query notification is sent by the configuration database to the master SRM indicating the changes to the default fault policy. The master SRM notifies any slave SRMs of any changes to the default fault policies specific to the boards on which they are executing, and the slave SRMs notify any LRMs of any changes to the default fault policies specific to their process. Going forward, the default fault policies - as modified by the configuration fault policy - are used to detect, track and respond to events or failures.

Alternatively, active queries may be established with the configuration database for configuration fault policies specific to each board type such that the slave SRMs are notified directly of changes to their default fault policies.

A fault policy (whether default or configured) is specific to a particular scope and descriptor and indicates a particular recovery action to take. As one example, a temporary patch may be required to handle hardware faults specific to a known bug in an integrated circuit chip. The configured fault policy, therefore, may indicate a scope of all



line cards, if the component is on all line cards, or only a specific type of line card that includes that component. The configured fault policy may also indicate that it is to be applied to all hardware faults with that scope, for example, the class will indicate hardware (HW) and all other fields will include wildcards (e.g., HW.\*.\*.\*). Instead, the configured fault policy may only indicate a particular type of hardware failure, for example, CRC errors on transmitted Ethernet packets (e.g., HW.Ethernet.TxCRC.\*).

### Redundancy:

As previously mentioned, a major concern for service providers is network downtime. In pursuit of “five 9’s availability” or 99.999% network up time, service providers must minimize network outages due to equipment (i.e., hardware) and all too common software failures. Developers of computer systems often use redundancy measures to minimize downtime and enhance system resiliency. Redundant designs rely on alternate or backup resources to overcome hardware and/or software faults. Ideally, the redundancy architecture allows the computer system to continue operating in the face of a fault with minimal service disruption, for example, in a manner transparent to the service provider’s customer.

Generally, redundancy designs come in two forms: 1:1 and 1:N. In a so-called “1:1 redundancy” design, a backup element exists for every active or primary element (i.e., hardware backup). In the event that a fault affects a primary element, a corresponding backup element is substituted for the primary element. If the backup element has not been in a “hot” state (i.e., software backup), then the backup element must be booted, configured to operate as a substitute for the failing element, and also provided with the “active state” of the failing element to allow the backup element to take over where the failed primary element left off. The time required to bring the software on the backup element to an “active state” is referred to as synchronization time. A long synchronization time can significantly disrupt system service, and in the case of a computer network device, if synchronization is not done quickly enough, then hundreds or thousands of network connections may be lost which directly impacts the service provider’s availability statistics and angers network customers.

To minimize synchronization time, many 1:1 redundancy schemes support hot backup of software, which means that the software on the backup elements mirror the software on the primary elements at some level. The “hotter” the backup element – that is, the closer the backup mirrors the primary – the faster a failed primary can be switched over or failed over to the backup. The “hottest” backup element is one that runs hardware and software simultaneously with a primary element conducting all operations in parallel with the primary element. This is referred to as a “1+1 redundancy” design and provides the fastest synchronization.

Significant costs are associated with 1:1 and 1+1 redundancy. For example, additional hardware costs may include duplicate memory components and printed circuit boards including all the components on those boards. The additional hardware may also require a larger supporting chassis. Space is often limited, especially in the case of network service providers who may maintain hundreds of network devices. Although 1:1 redundancy improves system reliability, it decreases service density and decreases the mean time between failures. Service density refers to the proportionality between the net output of a particular device and its gross hardware capability. Net output, in the case of a network device (e.g., switch or router), might include, for example, the number of calls handled per second. Redundancy adds to gross hardware capability but not to the net output and, thus, decreases service density. Adding hardware increases the likelihood of a failure and, thus, decreases the mean time between failures. Likewise, hot backup comes at the expense of system power. Each active element consumes some amount of the limited power available to the system. In general, the 1+1 or 1:1 redundancy designs provide the highest reliability but at a relatively high cost. Due to the importance of network availability, most network service providers prefer the 1+1 redundancy design to minimize network downtime.

In a 1:N redundancy design, instead of having one backup element per primary element, a single backup element or spare is used to backup multiple (N) primary elements. As a result, the 1:N design is generally less expensive to manufacture, offers greater service



the hardware backup element to float, that is, if a primary element fails over to the backup element, when the failed primary element is replaced, that new hardware may serve as the hardware backup.

#### Software Redundancy:

In its simplest form, a distributed redundancy system provides software redundancy (i.e., backup) with or without redundant (i.e., backup) hardware, for example, with or without using backup line card 16n as discussed earlier with reference to the logical to physical card table (Fig. 11a). Referring to Fig. 29, computer system 10 includes primary line cards 16a, 16b and 16c. Computer system 10 will likely include additional primary line cards; only three are discussed herein (and shown in Fig. 29) for convenience. As described above, to load instances of software applications, the NMS creates software load records (SLR) 128a-128n in configuration database 42. The SLR includes the name of a control shim executable file and a logical identification (LID) associated with a primary line card on which the application is to be spawned. In the current example, there either are no hardware backup line cards or, if there are, the slave SRM executing on that line card does not download and execute backup applications.

As one example, NMS 60 creates SLR 128a including the executable name atm\_cntrl.exe and card LID 30 (line card 16a), SLR 128b including atm\_cntrl.exe and LID 31 (line card 16b) and SLR 128c including atm\_cntrl.exe and LID 32 (line card 16c). The configuration database detects LID 30, 31 and 32 in SLRs 128a, 128b and 128c, respectively, and sends slave SRMs 37b, 37c and 37d (line cards 16a, 16b, and 16c) notifications including the name of the executable file (e.g., atm\_cntrl.exe) to be loaded. The slave SRMs then download and execute a copy of atm\_cntrl.exe 135 from memory 40 to spawn ATM controllers 136a, 136b and 136c.

Through the active query feature, the ATM controllers are sent records from group table (GT) 108' (Fig. 30) indicating how many instances of ATM each must start on their associated line cards. Group table 108' includes a primary line card LID field 447 and a backup line card LID field 449 such that, in addition to starting primary instances of

ATM, each primary line card also executes backup instances of ATM. For example, ATM controller 136a receives records 450-453 and 458-461 from group table 108' including LID 30 (line card 16a). Records 450-453 indicate that ATM controller 136a is to start four primary instantiations of ATM 464-467 (Fig. 29), and records 458-461 indicate that ATM controller 136a is to start four backup instantiations of ATM 468-471 as backup for four primary instantiations on LID 32 (line card 16c). Similarly, ATM controller 136b receives records 450-457 from group table 108' including LID 31 (line card 16b). Records 454-457 indicate that ATM controller 136b is to start four primary instantiations of ATM 472-475, and records 450-453 indicate that ATM controller 136b is to start four backup instantiations of ATM 476-479 as backup for four primary instantiations on LID 30 (line card 16a). ATM controller 136c receives records 454-461 from group table 108' including LID 32 (line card 16c). Records 458-461 indicate that ATM controller 136c is to start four primary instantiations of ATM 480-483, and records 454-457 indicate that ATM controller 136c is to start four backup instantiations of ATM 484-487 as backup for four primary instantiations on LID 31 (line card 16b). ATM controllers 136a, 136b and 136c then download atm.exe 138 and generate the appropriate number of ATM instantiations and also indicate to each instantiation whether it is a primary or backup instantiation. Alternatively, the ATM controllers may download atm.exe and generate the appropriate number of primary ATM instantiations and download a separate backup\_atm.exe and generate the appropriate number of backup ATM instantiations.

Each primary instantiation registers with its local name server 220b-220d, as described above, and each backup instantiation subscribes to its local name server 220b-220d for information about its corresponding primary instantiation. The name server passes each backup instantiation at least the process identification number assigned to its corresponding primary instantiation, and with this, the backup instantiation sends a message to the primary instantiation to set up a dynamic state check-pointing procedure. Periodically or asynchronously as state changes, the primary instantiation passes dynamic state information to the backup instantiation (i.e., check-pointing). In one embodiment, a Redundancy Manager Service available from Harris and Jefferies of Dedham,

Massachusetts may be used to allow backup and primary instantiations to pass dynamic state information. If the primary instantiation fails, it can be re-started, retrieve its last known dynamic state from the backup instantiation and then initiate an audit procedure (as described above) to resynchronize with other processes. The retrieval and audit process will normally be completed very quickly, resulting in no discernable service disruption.

Although each line card in the example above is instructed by the group table to start four instantiations of ATM, this is by way of example only. The user could instruct the NMS to set up the group table to have each line card start one or more instantiations and to have each line card start a different number of instantiations.

Referring to Fig. 31a-31c, if one or more of the primary processes on element 16a (ATM 464-467) experiences a software fault (Fig. 31b), the processor on line card 16a may terminate and restart the failing process or processes. Once the process or processes are restarted (ATM 464'-467', Fig. 31c), they retrieve a copy of the last known dynamic state (i.e., backup state) from corresponding backup processes (ATM 476-479) executing on line card 16b and initiate an audit process to synchronize retrieved state with the dynamic state of associated other processes. The backup state represents the last known active or dynamic state of the process or processes prior to termination, and retrieving this state from line card 16b allows the restarted processes on line card 16a to quickly resynchronize and continue operating. The retrieval and audit process will normally be completed very quickly, and in the case of a network device, quick resynchronization may avoid losing network connections, resulting in no discernable service disruption.

If, instead of restarting a particular application, the software fault experienced by line card 16a requires the entire element to be shut down and rebooted, then all of the processes executing on line card 16a will be terminated including backup processes ATM 468-471. When the primary processes are restarted, backup state information is retrieved from backup processes executing on line card 16b as explained above. Simultaneously, the restarted backup processes on line card 16a again initiate the check-pointing

procedure with primary ATM processes 480-483 executing on line card 16c to again serve as backup processes for these primary processes. Referring to Figs. 32a-32c, the primary processes executing on one line card may be backed-up by backup processes running on one or more other line cards. In addition, each primary process may be backed-up by one or more backup processes executing on one or more of the other line cards.

Since the operating system assigns each process its own memory block, each primary process may be backed-up by a backup process running on the same line card. This would minimize the time required to retrieve backup state and resynchronize if a primary process fails and is restarted. In a computer system that includes a spare or backup line card (described below), the backup state is best saved on another line card such that in the event of a hardware fault, the backup state is not lost and can be copied from the other line card. If memory and processor limitations permit, backup processes may run simultaneously on the same line card as the primary process and on another line card such that software faults are recovered from using local backup state and hardware faults are recovered from using remote backup state.

Where limitations on processing power or memory make full hot state backup impossible or impractical, only certain hot state data will be stored as backup. The level of hot state backup is inversely proportional to the resynchronization time, that is, as the level of hot state backup increases, resynchronization time decreases. For a network device, backup state may include critical information that allows the primary process to quickly resynchronize.

Critical information for a network device may include connection data relevant to established network connections (e.g., call set up information and virtual circuit information). For example, after primary ATM applications 464-467, executing on line card 16a, establish network connections, those applications send critical state information relevant to those connections to backup ATM applications 479-476 executing on line card 16b. Retrieving connection data allows the hardware (i.e., line card 16a) to send and

receive network data over the previously established network connections preventing these connections from being terminated / dropped.

Although ATM applications were used in the examples above, this is by way of example only. Any application (e.g., IP or MPLS), process (e.g., MCD or NS) or device driver (e.g., port driver) may have a backup process started on another line card to store backup state through a check-pointing procedure.

#### Hardware and Software Backup:

By adding one or more hardware backup elements (e.g., line card 16n) to the computer system, the distributed redundancy architecture provides both hardware and software backup. Software backup may be spread across all of the line cards or only some of the line cards. For example, software backup may be spread only across the primary line cards, only on one or more backup line cards or on a combination of both primary and backup line cards.

Referring to Fig. 33a, in the continuing example, line cards 16a, 16b and 16c are primary hardware elements and line card 16n is a spare or backup hardware element. In this example, software backup is spread across only the primary line cards. Alternatively, backup line card 16n may also execute backup processes to provide software backup. Backup line card 16n may execute all backup processes such that the primary elements need not execute any backup processes or line card 16n may execute only some of the backup processes. Regardless of whether backup line card 16n executes any backup processes, it is preferred that line card 16n be at least partially operational and ready to use the backup processes to quickly begin performing as if it was a failed primary line card.

There are many levels at which a backup line card may be partially operational. For example, the backup line card's hardware may be configured and device driver processes 490 loaded and ready to execute. In addition, the active state of the device drivers 492, 494, and 496 on each of the primary line cards may be stored as backup device driver





### Floating Backup Element:

Referring to Fig. 33c, when the fault is detected on line card 16a, diagnostic tests may be run to determine if the error was caused by software or hardware. If the fault is a software error, then line card 16a may again be used as a primary line card. If the fault is a hardware error, then line card 16a is replaced with a new line card 16a' that is booted and configured and again ready to be used as a primary element. In one embodiment, once line card 16a or 16a' is ready to serve as a primary element, a fail-over is initiated from line card 16n to line card 16a or 16a' as described above, including starting new primary processes 464''-467'' and retrieving active state from primary processes 464'-467' on line card 16n (or backup processes 476-479 on line card 16b). Backup processes 468''-471'' are also started, and those backup processes initiate a check-pointing procedure with primary processes 480-483 on line card 16c. This fail-over may cause the same level of service interruption as an actual failure.

Instead of failing-over from line card 16n back to line card 16a or 16a' and risking further service disruption, line card 16a or 16a' may serve as the new backup line card with line card 16n serving as the primary line card. If line cards 16b, 16c or 16n experience a fault, a fail-over to line card 16a is initiated as discussed above and the primary line card that failed (or a replacement of that line card) serves as the new backup line card. This is referred to as a "floating" backup element. Referring to Fig. 33d, if, for example, line card 16c experiences a fault, primary processes 480'-483' are started on backup line card 16a and active state is retrieved from backup processes 464'-467' on line card 16n. After line card 16c is rebooted or replaced and rebooted, it serves as the new backup line card for primary line cards 16a, 16b and 16n.

Alternatively, computer system 10 may be physically configured to only allow a line card in a particular chassis slot, for example, line card 16n, to serve as the backup line card. This may be the case where physically, the slot line card 16n is inserted within is wired to provide the necessary connections to allow line card 16n to communicate with each of the other line cards but no other slot provides these connections. In addition, even where the computer system is capable of allowing line cards in other chassis slots to act as the

backup line card, the person acting as network manager, may prefer to have the backup line card in each of his computer systems in the same slot. In either case, where only line card 16n serves as the backup line card, once line card 16a (or any other failed primary line card) is ready to act as a primary line card again, a fail-over, as described above, is initiated from line card 16n to the primary line card to allow line card 16n to again serve as a backup line card to each of the primary line cards.

#### Balancing Resources:

Typically, multiple processes or applications are executed on each primary line card. Referring to Fig. 34a, in one embodiment, each primary line card 16a, 16b, 16c executes four applications. Due to physical limitations (e.g., memory space, processor power), each primary line card may not be capable of fully backing up four applications executing on another primary line card. The distributed redundancy architecture allows backup processes to be spread across multiple line cards, including any backup line cards, to more efficiently use all system resources.

For instance, primary line card 16a executes backup processes 510 and 512 corresponding to primary processes 474 and 475 executing on primary line card 16b. Primary line card 16b executes backup processes 514 and 516 corresponding to primary processes 482 and 483 executing on primary line card 16c, and primary line card 16c executes backup processes 518 and 520 corresponding to primary processes 466 and 467 executing on primary line card 16a. Backup line card 16n executes backup processes 520, 522, 524, 526, 528 and 530 corresponding to primary processes 464, 465, 472, 473, 480 and 481 executing on each of the primary line cards. Having each primary line card execute backup processes for only two primary processes executing on another primary line card reduces the primary line card resources required for backup. Since backup line card 16n is not executing primary processes, more resources are available for backup. Hence, backup line card 16n executes six backup processes corresponding to six primary processes executing on primary line cards. In addition, backup line card 16n is partially operational and is executing device driver processes 490 and storing device driver backup state 498, 500 and 502 corresponding to the device drivers on each of the primary

elements and network connection data 504, 506 and 508 corresponding to the network connections established by each of the primary line cards.

Alternatively, each primary line card could execute more or less than two backup processes. Similarly, each primary line card could execute no backup processes and backup line card 16n could execute all backup processes. Many alternatives are possible and backup processes need not be spread evenly across all primary line cards or all primary line cards and the backup line card.

Referring to Fig. 34b, if primary line card 16b experiences a failure, device drivers 490 on backup line card 16n begins using the device driver state, for example, DDS 498, corresponding to the device drivers on primary line card 16b and the network connection data, for example, CD 506, corresponding to the connections established by primary line card 16b to continue transferring network data. Simultaneously, backup line card 16n starts substitute primary processes 510' and 512' corresponding to the primary processes 474 and 475 on failed primary line card 16b. Substitute primary processes 510' and 512' retrieve active state from backup processes 510 and 512 executing on primary line card 16a. In addition, the slave SRM on backup line card 16n informs backup processes 526 and 524 corresponding to primary processes 472 and 473 on failed primary line card 16b that they are now primary processes. The new primary applications then synchronize with the rest of the system such that new network connections may be established and old network connections torn down. That is, backup line card 16n begins operating as if it were primary line card 16b.

#### Multiple Backup Elements:

In the examples given above, one backup line card is shown. Alternatively, multiple backup line cards may be provided in a computer system. In one embodiment, a computer system includes multiple different primary line cards. For example, some primary line cards may support the Asynchronous Transfer Mode (ATM) protocol while others support the Multi-Protocol Label Switching (MPLS) protocol, and one backup line card may be provided for the ATM primary line cards and another backup line card may

be provided for the MPLS primary line cards. As another example, some primary line cards may support four ports while others support eight ports and one backup line card may be provided for the four port primaries and another backup line card may be provided for the eight port primaries. One or more backup line cards may be provided for each different type of primary line card.

#### Data Plane:

Referring to Fig. 35, a network device 540 includes a central processor 542, a redundant central processor 543 and a Fast Ethernet control bus 544 similar to central processors 12 and 13 and Ethernet 32 discussed above with respect to computer system 10. In addition, network device 540 includes forwarding cards (FC) 546a-546e, 548a-548e, 550a-550e and 552a-552e that are similar to line cards 16a-16n discussed above with respect to computer system 10. Network device 540 also includes (and computer system 10 may also include) universal port (UP) cards 554a-554h, 556a-556h, 558a-558h, and 560a-560h, cross-connection (XC) cards 562a-562b, 564a-564b, 566a-566b, and 568a-568b, and switch fabric (SF) cards 570a-570b. In one embodiment, network device 540 includes four quadrants where each quadrant includes five forwarding cards (e.g., 546a-546e), two cross connection cards (e.g., 562a-562b) and eight universal port cards (e.g., 554a-554h). Network device 540 is a distributed processing system. Each of the cards includes a processor and is connected to the Ethernet control bus. In addition, each of the cards are configured as described above with respect to line cards.

In one embodiment, the forwarding cards have a 1:4 hardware redundancy structure and distributed software redundancy as described above. For example, forwarding card 546e is the hardware backup for primary forwarding cards 546a-546d and each of the forwarding cards provide software backup. The cross-connection cards are 1:1 redundant. For example, cross-connection card 562b provides both hardware and software backup for cross-connection card 562a. Each port on the universal port cards may be 1:1, 1+1, 1:N redundant or not redundant at all depending upon the quality of service paid for by the customer associated with that port. For example, port cards 554e-554h may be the hardware and software backup cards for port cards 554a-554d in which



Ethernet control bus. The forwarding card also generates network control payloads and receives network control payloads from the central processor. The forwarding card sends any user data payloads from the cross-connection card or control information from itself or the central processor as path data to the switch fabric card. The switch fabric card then passes the path data to one of the forwarding cards in any quadrant, including the forwarding card that just sent the data to the switch fabric card. That forwarding card then sends the path data to the cross-connection card within its quadrant, which passes the path data to one of the port cards within its quadrant.

Referring to Fig. 36, in one embodiment, a universal port card 554a includes one or more ports 571a-571n connected to one or more transceivers 572a-572n. The user may connect an external network connection to each port. As one example, port 571a is connected to an ingress optical fiber 576a carrying an OC-48 SONET stream and an egress optical fiber 576b carrying an OC-48 SONET stream. Port 571a passes optical data from the SONET stream on fiber 576a to transceiver 572a. Transceiver 572a converts the optical data into electrical signals that it sends to a SONET framer 574a. The SONET framer organizes the data it receives from the transceiver into SONET frames. SONET framer 574a sends data over a telecommunications bus 578a to a serializer-deserializer (SERDES) 580a that serializes the data into four serial lines with twelve STS-1 time slots each and transmits the four serial lines to cross-connect card 562a.

Each cross-connection card is a switch that provides connections between port cards and forwarding cards within its quadrant. Each cross-connection card is programmed to transfer each serial line on each port card within its quadrant to a forwarding card within its quadrant or to serial line on a port card, including the port card that transmitted the data to the cross-connection card. The programming of the cross-connect card is discussed in more detail below under Policy Based Provisioning.

Each forwarding card (e.g., forwarding card 546c) receives SONET frames over serial lines from the cross-connection card in its quadrant through a payload extractor chip





priority traffic is transmitted, and in times of traffic congestion, the traffic management chips will ensure that low priority traffic is dropped prior to any high priority traffic. The traffic management chips also perform an address translation to add the address of the traffic management chip to which the data is going to be sent by the switch fabric card. The address corresponds to internal virtual circuits set up between forwarding cards by the software and available to the traffic management chips in tables.

The traffic management chips send the modified ATM cells to switch fabric interface chips (SFIF) 589a-589n that then transfer the ATM cells to switch fabric card 570a. The switch fabric card uses the address provided by the ingress traffic management chips to pass ATM cells to the appropriate egress traffic management chips (e.g., TM 590a-590n) on the various forwarding cards. In one embodiment, the switch fabric card 570a is a 320 Gbps, non-blocking fabric. Since each forwarding card serves as both an ingress and egress, the switching fabric card provides a high degree of flexibility in directing the data between any of the forwarding cards, including the forwarding card that sent the data to the switch fabric card.

When a forwarding card (e.g., forwarding card 546c) receives ATM cells from switch fabric card 570a, the egress traffic management chips re-translate the address of each cell and pass the cells to egress bridge chips (e.g., BG 592a-592b). The bridge chips pass the cells to egress ATM interface chips (e.g., ATM IF 594a-594n), and the ATM interface chips add a re-translated address to the payload representing an ATM virtual circuit. The ATM interface chips then send the data to the payload extractor chips (e.g., payload extractor 582a-582n) that separate, where necessary, the path data into STS-1 time slots and combine twelve STS-1 time slots into four serial lines and send the serial lines back through the cross-connection card to the appropriate port card.

The port card SERDES chips receive the serial lines from the cross-connection card and de-serialize the data and send it to SONET framer chips 574a-574n. The Framers properly format the SONET overhead and send the data back through the transceivers

that change the data from electrical to optical before sending it to the appropriate port and SONET fiber.

Although the port card ports above were described as connected to a SONET fiber carrying an OC-48 stream, other SONET fibers carrying other streams (e.g., OC-12) and other types of fibers and cables, for example, Ethernet, may be used instead. The transceivers are standard parts available from many companies, including Hewlett Packard Company and Sumitomo Corporation. The SONET framer may be a Spectra chip available from PMC-Sierra, Inc. in British Columbia. A Spectra 2488 has a maximum bandwidth of 2488 Mbps and may be coupled with a 1xOC48 transceiver coupled with a port connected to a SONET optical fiber carrying an OC-48 stream also having a maximum bandwidth of 2488 Mbps. Instead, four SONET optical fibers carrying OC-12 streams each having a maximum bandwidth of 622Mbps may be connected to four 1xOC12 transceivers and coupled with one Spectra 2488. Alternatively, a Spectra 4x155 may be coupled with four OC-3 transceivers that are coupled with ports connected to four SONET fibers carrying OC-3 streams each having a maximum bandwidth of 155 Mbps. Many variables are possible.

The SERDES chip may be a Telecommunications Bus Serializer (TBS) chip from PMC-Sierra, and each cross-connection card may include a Time Switch Element (TSE) from PMC-Sierra, Inc. Similarly, the payload extractor chips may be MACH 48 chips and the ATM interface chips may be ATLAS chips both of which are available from PMC-Sierra. Several chips are available from Extreme Packet Devices (EPD), a subsidiary of PMC-Sierra, including PP3 bridge chips and Data Path Element (DPE) traffic management chips. The switch fabric interface chips may include a Switch Fabric Interface (SIF) chip also from EPD. Other switch fabric interface chips are available from Abrizio, also a subsidiary of PMC-Sierra, including a data slice chip and an enhanced port processor (EPP) chip. The switch fabric card may also include chips from Abrizio, including a cross-bar chip and a scheduler chip.

Although the port cards, cross-connection cards and forwarding cards have been shown as separate cards, this is by way of example only and they may be combined into one or more different cards.

#### Multiple Redundancy Schemes:

Coupling universal port cards to forwarding cards through a cross-connection card provides flexibility in data transmission by allowing data to be transmitted from any path on any port to any port on any forwarding card. In addition, decoupling the universal port cards and the forwarding cards enables redundancy schemes (e.g., 1:1, 1+1, 1:N, no redundancy) to be set up separately for the forwarding cards and universal port cards. The same redundancy scheme may be set up for both or they may be different. As described above, the LID to PID card and port tables are used to setup the various redundancy schemes for the line cards (forwarding or universal port cards) and ports. Network devices often implement industry standard redundancy schemes, such as those defined by the Automatic Protection Switching (APS) standard. In network device 540 (Fig. 35), an APS standard redundancy scheme may be implemented for the universal port cards while another redundancy scheme is implemented for the forwarding cards.

Referring again to Fig. 35, further data transmission flexibility may be provided by connecting (i.e., connections 565) each cross-connection card 562a-562b, 564a-564b, 566a-566b and 568a-568b to each of the other cross-connection cards. Through connections 565, a cross-connection card (e.g., cross-connection card 562a) may transmit data between any port or any path on any port on a universal port card (e.g., universal port cards 554a-554h) in its quadrant to a cross-connection card (e.g., cross-connection card 568a) in any other quadrant, and that cross-connection card (e.g., cross-connection card 568a) may transmit the data to any forwarding card (e.g., forwarding cards 552a-552e) or universal port card (e.g., universal port cards 560a-560h) in its quadrant. Similarly, any cross-connection card may transmit data received from any forwarding card in its quadrant to any other cross-connection card and that cross-connection card may transmit the data to any universal port card port in its quadrant.





cards 570a-570b, the switch fabric cards may transmit data between any of the forwarding cards regardless of the underlying protocol.

Alternatively, the network manager may dedicate each quadrant to a specific protocol by putting forwarding cards in each quadrant according to the protocol they support. Within each quadrant then, one forwarding card may be a backup card for each of the other forwarding cards (1:N, for network device 540, 1:4). Protocol specific data received from ports or paths on ports on universal port cards within any quadrant may then be forwarded by one or more cross-connection cards to forwarding cards within the protocol specific quadrant. For instance, quadrant 1 may include forwarding cards for processing data transmissions using the ATM protocol, quadrant 2 may include forwarding cards for processing data transmissions using the IP protocol, quadrant 3 may include forwarding cards for processing data transmissions using the MPLS protocol and quadrant 4 may be used for processing data transmissions using the Frame Relay protocol. ATM data received on a port path is then transmitted by one or more cross-connection cards to a forwarding card in quadrant 1, while MPLS data received on another path on that same port or on a path in another port is transmitted by one or more cross-connection cards to a forwarding card in quadrant 3.

#### Policy Based Provisioning:

Unlike the switch fabric card, the cross-connection card does not examine header information in a payload to determine where to send the data. Instead, the cross-connection card is programmed to transmit payloads, for example, SONET frames, between a particular serial line on a universal port card port and a particular serial line on a forwarding card port regardless of the information in the payload. As a result, one port card serial line and one forwarding card serial line will transmit data to each other through the cross-connection card until that programmed connection is changed.

In one embodiment, connections established through a path table and service endpoint table (SET) in a configuration database are passed to path managers on port cards and service endpoint managers (SEMs) on forwarding cards, respectively. The path

managers and service endpoint managers then communicate with a cross-connect manager (CCM) on the cross-connection card in their quadrant to provide connection information. The CCM uses the connection information to generate a connection program table that is used by one or more components (e.g., a TSE chip 563) to program internal connection paths through the cross-connection card.

Typically, connections are fixed or are generated according to a predetermined map with a fixed set of rules. Unfortunately, a fixed set of rules may not provide flexibility for future network device changes or the different needs of different users / customers. Instead, within network device 540, each time a user wishes to enable / configure a path on a port on a universal port card, a Policy Provisioning Manager (PPM) 599 (Fig. 37) executing on central processor 542 selects the forwarding card port to which the port card port will be connected based on a configurable provisioning policy (PP) 603 in configuration database 42. The configurable provisioning policy may take into consideration many factors such as available system resources, balancing those resources and quality of service. Similar to other programs and files stored within the configuration database of computer system 10 described above, the provisioning policy may be modified while network device 540 is running to allow to policy to be changed according to a user's changing needs or changing network device system requirements.

When a user connects an external network connection to a particular port on a universal port card, the user notifies the NMS as to which port on which universal port card should be enabled, which path or paths should be enabled, and the number of time slots in each path. The user may also notify the NMS as to a new path and its number of time slots on an already enabled port that was not fully utilized or the user may notify the NMS of a modification to one or more paths on already enabled ports and the number of time slots required for that path or paths. With this information, the NMS fills in a Path table 600 (Figs. 37 and 38) and partially fills in a Service Endpoint Table (SET) 76' (Figs. 37 and 39).





card serial line 610. In one embodiment, the NMS fills in these fields with a particular value (e.g., zero), and in another embodiment, the NMS leaves these fields blank.

In either case, the particular value or a blank field causes the configuration database to send an active query notice to the PPM indicating a new path LID, quadrant number and service endpoint number. It is up to the PPM to decide which forwarding card, slice (i.e., payload extractor chip) and time slot (i.e., port) to assign to the new universal port card path. Once decided, the PPM fills in the SET Table fields. Since the user and NMS do not completely fill in the SET record, this may be referred to as a “self-completing configuration record.” Self-completing configuration records reduce the administrative workload of provisioning a network.

The SET and path table records may be automatically copied to persistent storage 21 to insure that if network device 540 is re-booted these configuration records are maintained. If the network device shuts down prior to the PPM filling in the SET record fields and having those fields saved in persistent storage, when the network device is rebooted, the SET will still include blank fields or fields with particular values which will cause the configuration database to again send an active query to the PPM.

When the forwarding card LID (e.g., 1667) corresponding, for example, to forwarding card 546c, is filled into the SET table, the configuration database sends an active query notification to an SEM (e.g., SEM 96i) executing on that forwarding card and corresponding to the assigned slice and/or time slots. The active query notifies the SEM of the newly assigned service endpoint number (e.g., SE 878) and the forwarding card slice (e.g., payload extractor 582a) and time slots (i.e., 3 time slots from one of the serial line inputs to payload extractor 582a) dedicated to the new path.

Path manager 597 and SEM 96i both send connection information to a cross-connection manager 605 executing on cross-connection card 562a – the cross-connection card within their quadrant. The CCM uses the connection information to generate a connection program table 601 and uses this table to program internal connections through one or

more components (e.g., a TSE chip 563) on the cross-connection card. Once programmed, cross-connection card 562a transmits data between new path LID 1666 on SONET fiber 576a connected to port 571a on universal port card 554a and the serial line input to payload extractor 582a on forwarding card 546c.

An active query notification is also sent to NMS database 61, and the NMS then displays the new system configuration to the user.

Alternatively, the user may choose which forwarding card to assign to the new path and notify the NMS. The NMS would then fill in the forwarding card LID in the SET, and the PPM would only determine which time slots and slice within the forwarding card to assign.

In the description above, when the PPM is notified of a new path, it compares the requirements of the new path to the available / unused forwarding card resources. If the necessary resources are not available, the PPM may signal an error. Alternatively, the PPM could move existing forwarding card resources to make the necessary forwarding card resources available for the new path. For example, if no payload extractor chip is completely available in the entire quadrant, one path requiring only one time slot is assigned to payload extractor chip 582a and a new path requires forty-eight time slots, the one path assigned to payload extractor chip 582a may be moved to another payload extractor chip, for example, payload extractor chip 582b that has at least one time slot available and the new path may be assigned all of the time slots on payload extractor chip 582a. Moving the existing path is accomplished by having the PPM modify an existing SET record. The new path is configured as described above.

Moving existing paths may result in some service disruption. To avoid this, the provisioning policy may include certain guidelines to hypothesize about future growth. For example, the policy may require small paths – for example, three or less time slots – to be assigned to payload extractor chips that already have some paths assigned instead of to completely unassigned payload extractor chips to provide a higher likelihood that

forwarding card resources will be available for large paths – for example, sixteen or more time slots -- added in the future.

#### Multi-Layer Network Device in One Telco Rack:

Referring again to Fig. 35, in one embodiment, each universal port card includes four ports, each of which is capable of being connected to an OC-48 SONET fiber. Since an OC-48 SONET fiber is capable of transferring data at 2.5 Giga bits per second (Gbps), each universal port card is capable of transferring data at 10 Gbps ( $4 \times 2.5 = 10$ ). With eight port cards per quadrant, the cross-connection card must be capable of transferring data at 80 Gbps. Typically, however, the eight port cards will be 1:1 redundant and only transfer 40 Gbps. In one embodiment, each forwarding card is capable of transferring 10 Gbps, and with five forwarding cards per quadrant, the switch fabric cards must be capable of transferring data at 200 Gbps. Typically, however, the five forwarding cards will be 1:N redundant and only transfer data at 40 Gbps. With four quadrants and full redundancy (1:1 for port cards and 1:N for forwarding cards), network device 540 is capable of transferring data at 160 Gbps.

In other embodiments, each port card includes one port capable of being connected to an OC-192 SONET fiber. Since OC-192 SONET fibers are capable of transferring data at 10 Gbps, a fully redundant network device 540 is again capable of transferring 160 Gbps. In the embodiment employing one OC-192 connection per port card, each port card may include one hundred and ninety-two logical DS3 connections using sub-rate data multiplexing (SDRM). In addition, each port card may differ in its number and type of ports to provide more or less data through put. As previously mentioned, ports other than SONET ports may be provided, for example, Ethernet ports, Plesiochronous Digital Hierarchy ports (i.e., DS0, DS1, DS3, E0, E1, E3, J0, J1, J3) and Synchronous Digital Hierarchy (SDH) ports (i.e., STM1, STM4, STM16, STM64).

The universal port cards and cross-connect cards in each quadrant are in effect a physical layer switch, and the forwarding cards and switch fabric cards are effectively an upper layer switch. Prior systems have packaged these two switches into separate network



port cards (UP) are located in the back portion of the chassis where external network attachments / cables may be easily connected.

The chassis also supports switch fabric cards 570a and 570b. As shown, each switch fabric card may include multiple switch fabric (SF) cards and a switch scheduler (SS) card. In addition, the chassis supports multiple central processor cards (542 and 543, Fig. 35). Instead of having a single central processor card, the external control functions and the internal control functions may be separated onto different cards as described in U.S. Patent Application Serial Number \_\_\_, filed May 20, 2000 and entitled "Functional Separation of Internal and External Controls in Network Devices", which is hereby incorporated herein by reference. As shown, the chassis may support internal control (IC) processor cards 542a and 543a and external control (EC) processor cards 542b and 543b. Auxiliary processor (AP) cards 542c and 543c are provided for future expansion to allow more external control cards to be added, for example, to handle new upper layer protocols. In addition, a management interface (MI) card 621 for connecting to an external network management system (62, Fig. 35) is also provided.

The chassis also support two mid-plane printed circuit boards 622a and 622b (Fig. 41c) located toward the middle of chassis 620. Mid-plane 622a is located in the top portion of chassis 620 and is connected to quadrant 1 and 2 forwarding cards 546a-546e and 548a-548e, universal port cards 554a-554h and 556a-556h, and cross-connection cards 562a-562b and 564a-564b. Similarly, mid-plane 622b is located in the bottom portion of chassis 620 and is connected to quadrant 3 and 4 forwarding cards 550a-550e and 552a-552e, universal port cards 558a-558h and 560a-560h, and cross-connection cards 566a-566b and 568a-568b. Through each mid-plane, the cross-connection card in each quadrant may transfer network packets between any of the universal port cards in its quadrant and any of the forwarding cards in its quadrant. In addition, through mid-plane 622a the cross-connection cards in quadrants 1 and 2 may be connected to allow for transfer of network packets between any forwarding cards and port cards in quadrants 1 and 2, and through mid-plane 622b the cross-connection cards in quadrants 3 and 4 may

be connected to allow for transfer of network packets between any forwarding cards and port cards in quadrants 3 and 4.

Mid-plane 622a is also connected to external control processor cards 542b and 543b and management interface card 621. Mid-plane 622b is also connected to auxiliary processor cards 542c and 543c.

Switch fabric cards 570a and 570b are located in the back portion of chassis 620, approximately mid-way between the top and bottom of the chassis. The switch fabric cards are connected to both mid-planes 622a and 622b to allow the switch fabric cards to transfer signals between any of the forwarding cards in any quadrant. In addition, the cross-connection cards in quadrants 1 and 2 may be connected through the mid-planes and switch fabric cards to the cross-connection cards in quadrants 3 and 4 to enable network packets to be transferred between any universal port card and any forwarding card.

To provide for better routing efficiency through mid-plane 622b, forwarding cards 550a-550e and 552a-552e and cross-connection cards 566a-566b and 568a-568b in quadrants 3 and 4, located in the bottom portion of the chassis, are flipped over when plugged into mid-plane 622b. This permits the switch fabric interface 589a-589n on each of the lower forwarding cards to be oriented nearest the switch fabric cards and the cross-connection interface 582a-582n on each of the lower forwarding cards to be oriented nearest the cross-connection cards in quadrants 3 and 4. This orientation avoids having to cross switch fabric and cross-connection etches in mid-plane 622b.

Typically, airflow for cooling a network device is brought in at the bottom of the device and released at the top of the device. For example, in the back portion of chassis 620, a fan tray (FT) 626 pulls air into the device from the bottom portion of the device and a fan tray 628 blows air out of the top portion of the device. When the lower forwarding cards are flipped over, the airflow / cooling pattern is reversed. To accommodate this reversal, fan trays 630 and 632 pull air into the middle portion of the device and then fan trays 634

and 636 pull the air upwards and downwards, respectively, and blow the heated air out the top and bottom of the device, respectively.

The quadrant 3 and 4 universal port cards 558a-558h and 560a-560h may also be flipped over to orient the port card's cross-connection interface nearest the cross-connection cards and more efficiently use the routing resources. It is preferred, however, not to flip the universal port cards for serviceability reasons and airflow issues. The network managers at the telco site expect network attachments / cables to be in a certain pattern. Reversing this pattern could cause confusion in a large telco site with many different types of network devices. Also, flipping the port cards will change the airflow and cooling pattern and require a similar airflow pattern and fan tray configuration as implemented in the front of the chassis. However, with the switch fabric and internal control processor cards in the middle of the back portion of the chassis, it may be impossible to implement this fan tray configuration.

Referring to Fig. 42, mid-plane 622a includes connectors 638 mounted on the back side of the mid-plane ("back mounted") for the management interface card, connectors 640a-640d mounted on the front side of the mid-plane ("front mounted") for the quadrant 1 and 2 cross-connection cards, and front mounted connectors 642a-642b for the external control processor cards. Multiple connectors may be used for each card. Mid-plane 622a also includes back mounted connectors 644a-644p for the quadrant 1 and 2 universal port cards and front mounted connectors 646a-646j for the quadrant 1 and 2 forwarding cards.

Both mid-planes 622a and 622b include back mounted connectors 648a-648d for the switch fabric cards and back mounted connectors 650a-650d for the internal control cards. Mid-plane 622b further includes front, reverse mounted connectors 652a-652j for the quadrant 3 and 4 forwarding cards and back mounted connectors 654a-654p for the quadrant 3 and 4 universal port cards. In addition, mid-plane 622b also includes front, reverse mounted connectors 656a-656d for the quadrant 3 and 4 cross-connection cards and front mounted connectors 658a-658b for the auxiliary processor cards.

Combining both physical layer switch/router subsystems and upper layer switch/router subsystems in one network device allows for intelligent layer 1 switching. For example, the network device may be used to establish dynamic network connections on the layer 1 network to better utilize resources as service subscriptions change. In addition, network management is greatly simplified since the layer 1 and multiple upper layer networks may be managed by the same network management system and grooming fees are eliminated. Combining the physical layer switch/router and upper layer switch/routers into a network device that fits into one telco rack provides a less expensive network device and saves valuable telco site space.

Splitting the cross-connection function into four separate cards / quadrants enables the cross-connection routing requirements to be spread between the two mid-planes and alleviates the need to route cross-connection signals through the center of the device where the switch fabric is routed. In addition, segmenting the cross-connection function into multiple, independent subsystems allows customers / network managers to add functionality to network device 540 in pieces and in accordance with network service subscriptions. When a network device is first installed, a network manager may need only a few port cards and forwarding cards to service network customers. The modularity of network device 540 allows the network manager to purchase and install only one cross-connection card and the required number of port and forwarding cards. As the network becomes more subscribed, the network manager may add forwarding cards and port cards and eventually additional cross-connection cards. Since network devices are often very expensive, this modularity allows network managers to spread the cost of the system out in accordance with new service requests. The fees paid by customers to the network manager for the new services can then be applied to the cost of the new cards.

Although the embodiment describes the use of two mid-planes, it should be understood that more than two mid-planes may be used. Similarly, although the embodiment described flipped / reversed the forwarding cards and cross-connection cards in the lower



half of the chassis, alternatively, the forwarding cards and cross-connection cards in the upper half of the chassis could be flipped.

#### Distributed Switch Fabric:

A network device having a distributed switch fabric locates a portion of the switch fabric functionality on cards separate from the remaining / central switch fabric functionality. For example, a portion of the switch fabric may be distributed on each forwarding card. There are a number of difficulties associated with distributing a portion of the switch fabric. For instance, distributing the switch fabric makes mid-plane / back-plane routing more difficult which further increases the difficulty of fitting the network device into one telco rack, switch fabric redundancy and timing are also made more difficult, valuable forwarding card space must be allocated for switch fabric components and the cost of each forwarding card is increased. However, since the entire switch fabric need not be included in a minimally configured network device, the cost of the minimal configuration is reduced allowing network service providers to more quickly recover the initial cost of the device. As new services are requested, additional functionality, including both forwarding cards (with additional switch fabric functionality) and universal port cards may be added to the network device to handle the new requests, and the fees for the new services may be applied to the cost of the additional functionality. Consequently, the cost of the network device more closely tracks the service fees received by network providers.

Referring again to Fig. 36, as described above, each forwarding card (e.g., 546c) includes traffic management chips (e.g., 588a-588n and 590a-590b) that ensure high priority network data / traffic (e.g., voice) is transferred faster than lower priority traffic (e.g., e-mail). Each forwarding card also includes switch fabric interface (SFIF) chips (e.g., 589a-589n) that transfer network data between the traffic management chips and the switch fabric cards 570a-570b.

Referring also to Fig. 43, forwarding card 546c includes traffic management (TM) chips 588n and 590a and SFIF chips 589, and forwarding card 550a includes traffic management chips 659a and 659b and SFIF chips 660. (Fig. 43 includes only two



hold off sending more data. Back pressure may be applied to all forwarding cards when a new switch fabric control card is added to the network device, as described below.

The traffic management chips forward network data in predefined segments to the SIF chips. In the case of ATM data, each ATM cell is a segment. In the case of IP and MPLS, where the amount of network data in each packet may vary, the data is first arranged into appropriately sized segments before being sent to the SIF chips. This may be accomplished through segmentation and reassembly (SAR) chips (not shown).

When the SIF chip receives a segment of network data, it organizes the data into a segment consistent with that expected by the switch fabric components, including any required header information. The SIF chip may be a PMC9324-TC chip available from Extreme Packet Devices (EPD), a subsidiary of PMC-Sierra, and the data slice chips may be PM9313-HC chips and the EPP chip may be a PM9315-HC chip available from Abrizio, also a subsidiary of PMC-Sierra. In this case, the SIF chip organizes each segment of data – including header information -- in accordance with a line-card-to-switch two (LCS-2) protocol. The SIF chip then divides each data segment into twelve slices and sends two slices to each data slice chip 662a-662f. Two slices are sent because each data slice chip includes the functionality of two data slices.

When the data slice chips receive the LCS segments, the data slice chips strip off the header information, including both a destination address and quality of service (QoS) information, and send the header information to the local EPP chip. Alternatively, the SIF chip may send the header information directly to the EPP chip and send only data to the data slice chips. However, the manufacturer teaches that the SIF chip should be on the forwarding card and the EPP and data slice chips should be on a separate switch fabric card within the network device or in a separate box connected to the network device. Minimizing connections between cards is important, and where the EPP and data slice chips are not on the same card as the SIF chips, the header information is sent with the data by the SIF chip to reduce the required inter-card connections, and the data slice chips then strip off this information and send it to the EPP chip.

The EPP chips on all of the forwarding cards communicate and synchronize through cross-bar chips 674a-674b on control card 666. For each time interval (e.g., every 40 nanoseconds, "ns"), the EPP chips inform the scheduler chip as to which data segment they would like to send and the data slice chips send a segment of data previously set up by the scheduler and EPP chips. The EPP chips and the scheduler use the destination addresses to determine if there are any conflicts, for example, to determine if two or more forwarding cards are trying to send data to the same forwarding card. If a conflict is found, then the quality of service information is used to determine which forwarding card is trying to send the higher priority data. The highest priority data will likely be sent first. However, the scheduler chips include an algorithm that takes into account both the quality of service and a need to keep the switch fabric data cards 668a-668d full (maximum data through put). Where a conflict exists, the scheduler chip may inform the EPP chip to send a different, for example, lower priority, data segment from the data slice chip buffers or to send an empty data segment during the time interval.

Scheduler chip 670 informs each of the EPP chips which data segment is to be sent and received in each time interval. The EPP chips then inform their local data slice chips as to which data segments are to be sent in each interval and which data segments will be received in each interval. As previously mentioned, the forwarding cards each send and receive data. The data slice chips include small buffers to hold certain data (e.g., lower priority) while other data (e.g., higher priority) data is sent and small buffers to store received data. The data slice chips also include header information with each segment of data sent to the switch fabric cards. The header information is used by cross-bar chips 672a-672i (only cross-bar chips 672a-672f are shown) to switch the data to the correct forwarding card. The cross-bar chips may be PM9312-UC chips and the scheduler chip may be a PM9311-UC chip both of which are available from Abrizio.

Specifications for the EPD, Abrizio and PMC-Sierra chips may be found at [www.pmc-sierra.com](http://www.pmc-sierra.com) and are hereby incorporated herein by reference.

### Distributed Switch Fabric Timing:

As previously mentioned, a segment of data (e.g., an ATM cell) is transferred between the data slice chips through the cross-bar chips every predetermined time interval. In one embodiment, this time interval is 40ns and is established by a 25MHz start of segment (SOS) signal. A higher frequency clock (e.g., 200 MHz, having a 5ns time interval) is used by the data slice and cross-bar chips to transfer the bits of data within each segment such that all the bits of data in a segment are transferred within one 40ns interval. More specifically, in one embodiment, each switch fabric component multiplies the 200 MHz clock signal by four to provide an 800 MHz internal clock signal allowing data to be transferred through the data slice and cross-bar components at 320 Gbps. As a result, every 40ns one segment of data (e.g., an ATM cell) is transferred. It is crucial that the EPP, scheduler, data slice and cross-bar chips transfer data according to the same / synchronized timing signals (e.g., clock and SOS), including both frequency and phase. Transferring data at different times, even slightly different times, may lead to data corruption, the wrong data being sent and/or a network device crash.

When distributed signals (e.g., reference SOS or clock signals) are used to synchronize actions across multiple components (e.g., the transmission of data through a switch fabric), any time-difference in events (e.g., clock pulse) on the distributed signals is generally termed “skew”. Skew between distributed signals may result in the actions not occurring at the same time, and in the case of transmission of data through a switch fabric, skew can cause data corruption and other errors. Many variables can introduce skew into these signals. For example, components used to distribute the clock signal introduce skew, and etches on the mid-plane(s) introduce skew in proportion to the differences in their length (e.g., about 180 picoseconds per inch of etch in FR 4 printed circuit board material).

To minimize skew, one manufacturer teaches that all switch fabric components (i.e., scheduler, EPP, data slice and cross-bar chips) should be located on centralized switch fabric cards. That manufacturer also suggests distributing a central clock reference signal (e.g., 200 MHz) and a separate SOS signal (e.g., 25 MHz) to the switch fabric



etches for the reference timing signals from both the primary and redundant central timing subsystems must be matched. Compounding this with a fast clock signal and low skew component requirements makes distributing the timing very difficult.

The network device of the present invention, though difficult, includes two synchronized central timing subsystems (CTS) 673 (one is shown in Fig. 43). The etch lengths of reference timing signals from both central timing subsystems are matched to within, for example, +/- 50 mils, and both central timing subsystems distribute only reference start of segment (SOS) signals to a local timing subsystem (LTS) 665 on each forwarding card and switch fabric card. The LTSs use the SOS reference signals to generate both an SOS signal and a higher frequency clock signal. This adds components and complexity to the LTSs, however, distributing only the SOS reference signals and not both the SOS and clock reference signals significantly reduces the number of reference timing signals that must be routed across the mid-plane on matched etch lengths.

Both electro-magnetic radiation and electro-physical limitations prevent the 200 MHz reference clock signal from being widely distributed as required in a network device implementing distributed switch fabric subsystems. Such a fast reference clock increases the overall noise level generated by the network device and wide distribution may cause the network device to exceed Electro-Magnetic Interference (EMI) limitations. Clock errors are often measured as a percentage of the clock period, the smaller the clock period (5ns for a 200 MHz clock), the larger the percentage of error a small skew can cause. For example, a skew of 3ns represents a 60% error for a 5ns clock period but only a 7.5% error for a 40ns clock period. Higher frequency clock signals (e.g., 200 MHz) are susceptible to noise error and clock skew. The SOS signal has a larger clock period than the reference clock signal (40ns versus 5ns) and, thus, is less susceptible to noise error and reduces the percentage of error resulting from clock skew.

As previously mentioned, the network device may include redundant switch fabric cards 570a and 570b (Fig. 36) and as described above with reference to Fig. 43, each switch fabric card 570a and 570b may include a control card and four or more data cards.

Referring to Fig. 44, network device 540 may include switch fabric control card 666 (part of central switch fabric 570a) and redundant switch fabric control card 667 (part of redundant switch fabric 570b). Each control card 666 and 667 includes a central timing subsystem (CTS) 673. One CTS behaves as the master and the other CTS behaves as a slave and locks its output SOS signal to the master's output SOS signal. In one embodiment, upon power-up or system re-boot the CTS on the primary switch fabric control card 666 begins as the master and if a problem occurs with the CTS on the primary control card, then the CTS on redundant control card 667 takes over as master without requiring a switch over of the primary switch fabric control card.

Still referring to Fig. 44, each CTS sends a reference SOS signal to the LTSs on each forwarding card, switch fabric data cards 668a-668d and redundant switch fabric data cards 669a-669b. In addition, each CTS sends a reference SOS signal to the LTS on its own switch fabric control card and the LTS on the other switch fabric control card. As described in more detail below, each LTS then selects which reference SOS signal to use. Each CTS 673 also sends a reference SOS signal to the CTS on the other control card. The master CTS ignores the reference SOS signal from the slave CTS but the slave CTS locks its reference SOS signal to the reference SOS signal from the master, as described below. Locking the slave SOS signal to the master SOS signal synchronizes the slave signal to the master signal such that in the event that the master CTS fails and the LTSs switchover to the slave CTS reference SOS signal and the slave CTS becomes the master CTS, minimal phase change and no signal disruption is encountered between the master and slave reference SOS signals received by the LTSs.

Each of the CTS reference SOS signals sent to the LTSs and the other CTS over mid-plane etches are the same length (i.e., matched) to avoid introducing skew. The CTS may be on its own independent card or any other card in the system. Even when it is located on a switch fabric card, such as the control card, that has an LTS, the reference SOS signal is routed through the mid-plane with the same length etch as the other reference SOS signals to avoid adding skew.



### Central Timing Subsystem (CTS):

Referring to Fig. 45, central timing subsystem (CTS) 673 includes a voltage controlled crystal oscillator (VCXO) 676 that generates a 25MHz reference SOS signal 678. The SOS signal must be distributed to each of the local timing subsystems (LTSs) and is, thus, sent to a first level clock driver 680 and then to second level clock drivers 682a-682d that output reference SOS signals SFC\_BENCH\_FB and SFC\_REF1 – SFC\_REFn. SFC\_BENCH\_FB is a local feedback signal returned to the input of the CTS. One of SFC\_REF1 - SFC\_REFn is sent to each LTS, the other CTS, which receives it on SFC\_SYNC, and one is routed over a mid-plane and returned as a feedback signal SFC\_FB to the input of the CTS that generated it. Additional levels of clock drivers may be added as the number of necessary reference SOS signals increases.

VCXO 676 may be a VF596ES50 25MHz LVPECL available from Conner-Winfield. Positive Emitter Coupled Logic (PECL) is preferred over Transistor-Transistor Logic (TTL) for its lower skew properties. In addition, though it requires two etches to transfer a single clock reference -- significantly increasing routing resources --, differential PECL is preferred over PECL for its lower skew properties and high noise immunity. The clock drivers are also differential PECL and may be one to ten (1:10) MC100 LVEP111 clock drivers available from On Semiconductor. A test header 681 may be connected to clock driver 680 to allow a test clock to be input into the system.

Hardware control logic 684 determines (as described below) whether the CTS is the master or slave, and hardware control logic 684 is connected to a multiplexor (MUX) 686 to select between a predetermined voltage input (i.e., master voltage input) 688a and a slave VCXO voltage input 688b. When the CTS is the master, hardware control logic 684 selects predetermined voltage input 688a from discrete bias circuit 690 and slave VCXO voltage input 688b is ignored. The predetermined voltage input causes VCXO 676 to generate a constant 25MHz SOS signal; that is, the VCXO operates as a simple oscillator.

Hardware control logic may be implemented in a field programmable gate array (FPGA) or a programmable logic device (PLD). MUX 686 may be a 74CBTLV3257 FET 2:1 MUX available from Texas Instruments.

When the CTS is the slave, hardware control logic 684 selects slave VCXO voltage signal 688b. This provides a variable voltage level to the VCXO that causes the output of the VCXO to track or follow the SOS reference signal from the master CTS. Referring still to Fig. 45, the CTS receives the SOS reference signal from the other CTS on SFC\_SYNC. Since this is a differential PECL signal, it is first passed through a differential PECL to TTL translator 692 before being sent to MUX 697a within dual MUX 694. In addition, two feedback signals from the CTS itself are supplied as inputs to the CTS. The first feedback signal SFC\_FB is an output signal (e.g., one of SFC\_REF1-SFC\_REFn) from the CTS itself which has been sent out to the mid-plane and routed back to the switch fabric control card. This is done so that the feedback signal used by the CTS experiences identical conditions as the reference SOS signal delivered to the LTSs and skew is minimized. The second feedback signal SFC\_BENCH\_FB is a local signal from the output of the CTS, for example, clock driver 682a. SFC\_BENCH\_FB may be used as the feedback signal in a test mode, for example, when the control card is not plugged into the network device chassis and SFC\_SB is unavailable. SFC\_BENCH\_FB and SFC\_FB are also differential PECL signals and must be sent through translators 693 and 692, respectively, prior to being sent to MUX 697b within dual MUX 694. Hardware control logic 684 selects which inputs are used by MUX 694 by asserting signals on REF\_SEL(1:0) and FB\_SEL(1:0). In regular use, inputs 696a and 696b from translator 692 are selected. In test modes, grounded inputs 695a, test headers 695b or local feedback signal 698 from translator 693 may be selected. Also in regular use (and in test modes where a clock signal is not inserted through the test headers), copies of the selected input signals are provided on the test headers.

The reference output 700a and the feedback output 700b are then sent from the MUX to phase detector circuit 702. The phase detector compares the rising edge of the two input signals to determine the magnitude of any phase shift between the two. The phase



components connected to that signal stop functioning causing the entire switch fabric to fail.

Slow phase changes on the reference SOS signals from both the master and slave CTSs are also important when LTSs switch over from using the master CTS reference signal to using the slave CTS reference signal. For example, if the reference SOS signal from the master CTS dies or other problems are detected (e.g., a clock driver dies), then the slave CTS switches over to become the master CTS and each of the LTSs begin using the slave CTS' reference SOS signal. For these reasons, it is important that the slave CTS reference SOS signal be synchronized to the master reference signal but not quickly follow large phase shifts in the master reference signal.

It is not necessary for every LTS to use the reference SOS signals from the same CTS. In fact, some LTSs may use reference SOS signals from the master CTS while one or more are using the reference SOS signals from the slave CTS. In general, this is a transitional state prior to or during switch over. For example, one or more LTSs may start using the slave CTS's reference SOS signal prior to the slave CTS switching over to become the master CTS.

It is important for both the CTSs and the LTSs to monitor the activity of the reference SOS signals from both CTSs such that if there is a problem with one, the LTSs can begin using the other SOS signal immediately and/or the slave CTS can quickly become master. Reference output signal 700a – the translated reference SOS signal sent from the other CTS and received on SFC\_SYNC -- is sent to an activity detector circuit 708. The activity detector circuit determines whether the signal is active – that is, whether the signal is “stuck at” logic 1 or logic 0. If the signal is not active (i.e., stuck at logic 1 or 0), the activity detector sends a signal 683a to hardware control logic 684 indicating that the signal died. The hardware control logic may immediately select input 688a to MUX 686 to change the CTS from slave to master. The hardware control logic also sends an interrupt to a local processor 710 and software being executed by the processor detects

the interrupt. Hardware control allows the CTS switch over to happen very quickly before a bad clock signal can disrupt the system.

Similarly, an activity detector 709 monitors the output of the first level clock driver 680 regardless of whether the CTS is master or slave. Instead, the output of one the second level clock drivers could be monitored, however, a failure of a different second level clock will not be detected. SFC\_REF\_ACTIVITY is sent from the first level clock driver to differential PECL to TTL translator 693 and then as FABRIC\_REF\_ACTIVITY to activity detector 709. If activity detector 709 determines that the signal is not active, which may indicate that the clock driver, oscillator or other component(s) within the CTS have failed, then it sends a signal 683b to the hardware control logic. The hardware control logic asserts KILL\_CLKTREE to stop the clock drivers from sending any signals and notifies a processor chip 710 on the switch fabric control card through an interrupt. Software being executed by the processor chip detects the interrupt. The slave CTS activity detector 708 detects a dead signal from the master CTS either before or after the hardware control logic sends KILL\_CLKTREE and asserts error signal 683a to cause the hardware control logic to change the input selection on MUX 686 from 688b to 688a to become the master CTS. As described below, the LTSs also detect a dead signal from the master CTS either before or after the hardware control logic sends KILL\_CLKTREE and switch over to the reference SOS signal from the slave CTS either before or after the slave CTS switches over to become the master.

As previously mentioned, in the past, a separate, common clock selection signal or etch was sent to each card in the network device to indicate whether to use the master or slave clock reference signal. This approach required significant routing resources, was under software control and resulted in every load selecting the same source at any given time. Hence, if a clock signal problem was detected, components had to wait for the software to change the separate clock selection signal before beginning to use the standby clock signal and all components (i.e., loads) were always locked to the same source. This delay can cause data corruption errors, switch fabric failure and a network device crash.



predetermined threshold, then the phase detector asserts an OOL signal to the hardware control logic. The hardware control logic may immediately change the input to MUX 686 to cause the slave CTS to switch over to Master CTS and send an interrupt to the processor, or the hardware control logic may only send the interrupt and wait for software (e.g., the SRM) to determine whether the slave CTS should switch over to master.

#### Master / Slave CTS Control:

In order to determine which CTS is the master and which is the slave, hardware control logic 684 implements a state machine. Each hardware control logic 684 sends an IM\_THE\_MASTER signal to the other hardware control logic 684 which is received as a YOU\_THE\_MASTER signal. If the IM\_THE\_MASTER signal – and, hence, the received YOU\_THE\_MASTER signal -- is asserted then the CTS sending the signal is the master (and selects input 688a to MUX 686, Fig. 45) and the CTS receiving the signal is the slave (and selects input 688b to MUX 686). Each IM\_THE\_MASTER / YOU\_THE\_MASTER etch is pulled down to ground on the mid-planes such that if one of the CTSs is missing, the YOU\_THE\_MASTER signal received by the other CTS will be a logic 0 causing the receiving CTS to become the master. This situation may arise, for example, if a redundant control card including the CTS is not inserted within the network device. In addition, each of the hardware control logics receive SLOT\_ID signals from pull-down/pull-up resistors on the chassis mid-plane indicating the slot in which the switch fabric control card is inserted.

Referring to Fig. 46, on power-up or after a system or card or CTS re-boot, the hardware control logic state machine begins in INIT/RESET state 0 and does not assert IM\_THE\_MASTER. If the SLOT\_ID signals indicate that the control card is inserted in a preferred slot (e.g., slot one), and the received YOU\_THE\_MASTER is not asserted (i.e., 0), then the state machine transitions to the ONLINE state 3 and the hardware control logic asserts IM\_THE\_MASTER indicating its master status to the other CTS and selects input 688a to MUX 686. While in the ONLINE state 3, if a failure is detected or the software tells the hardware logic to switch over, the state machine enters the OFFLINE state 1 and the hardware control logic stops asserting IM\_THE\_MASTER and

asserts KILL\_CLKTREE. While in the OFFLINE state 1, the software may reset or reboot the control card or just the CTS and force the state machine to enter the STANDBY state 2 as the slave CTS and the hardware control logic stops asserting KILL\_CLKTREE and selects input 688b to MUX 686.

While in INIT/RESET state 0, if the SLOT\_ID signals indicate that the control card is inserted in a non-preferred slot, (e.g., slot 0), then the state machine will enter STANDBY state 2 as the slave CTS and the hardware control logic will not assert IM\_THE\_MASTER and will select input 688b to MUX 686. While in INIT/RESET state 0, even if the SLOT\_ID signals indicate that the control card is inserted in the preferred slot, if YOU\_THE\_MASTER is asserted, indicating that the other CTS is master, then the state machine transfers to STANDBY state 2. This situation may arise after a failure and recovery of the CTS in the preferred slot (e.g., reboot, reset or new control card).

While in the STANDBY state 2, if the YOU\_THE\_MASTER signal becomes zero (i.e., not asserted), indicating that the master CTS is no longer master, the state machine will transition to ONLINE state 3 and the hardware control logic will assert IM\_THE\_MASTER and select input 688a to MUX 686 to become master. While in ONLINE state 3, if the YOU\_THE\_MASTER signal is asserted and SLOT\_ID indicating slot 0 the state machine enters STANDBY state 2 and the hardware control logic stops asserting IM\_THE\_MASTER and selects input 688b to MUX 686. This is the situation where the original master CTS is back up and running. The software may reset the state machine at any time or set the state machine to a particular state at any time.

#### Local Timing Subsystem:

Referring to Fig. 47, each local timing subsystem (LTS) 665 receives a reference SOS signal from each CTS on SFC\_REFA and SFC\_REFB. Since these are differential PECL signals, each is passed through a differential PECL to TTL translator 714a or 714b, respectively. A feedback signal SFC\_FB is also passed from the LTS output to both translators 714a and 714b. The reference signal outputs 716a and 716b are fed into a first





The divider component may be a SY100EL34L divider by Synergy Semiconductor Corporation.

Reference signals 716a and 716b from translator 714a are also sent to activity detectors 734a and 734b, respectively. These activity detectors perform the same function as the activity detectors in the CTSs and assert error signals `ref_a_los` or `ref_b_los` to the LTS hardware control logic if reference signal 716a or 716b, respectively, die. On power-up, reset or reboot, a state machine (Fig. 48) within the LTS hardware control logic starts in INIT/RESET state 0. Arbitrarily, reference signal 716a is the first signal considered. If activity detector 734a is not sending an error signal (i.e., `ref_a_los` is 0), indicating that that reference signal 716a is active, then the state machine changes to REF\_A state 2 and sends signals over `REF_SEL(1:0)` to MUX 717 to select reference input 716a and sends signals over `FB_SEL(1:0)` to MUX 720 to select feedback input 719a. While in INIT/RESET state 0, if `ref_a_los` is asserted, indicating no signal on reference 716a, and if `ref_b_los` is not asserted, indicating there is a signal on reference 716b, then the state machine changes to REF\_B state 1 and changes `REF_SEL(1:0)` and `FB_SEL(1:0)` to select reference input 716b and feedback signal 719b.

While in REF\_A state 2, if activity detector 734a detects a loss of reference signal 716a and asserts `ref_a_los`, the state machine will change to REF\_B state 1 and change `REF_SEL(1:0)` and `FB_SEL(1:0)` to select inputs 716b and 719b. Similarly, while in REF\_B state 1, if activity detector 734b detects a loss of signal 716b and asserts `ref_b_los`, the state machine will change to REF\_A state 2 and change `REF_SEL(1:0)` and `FB_SEL(1:0)` to select inputs 716a and 719a. While in either REF\_A state 2 or REF\_B state 1, if both `ref_a_los` and `ref_b_los` are asserted, indicating that both reference SOS signals have died, the state machine changes back to INIT/RESET state 0 and change `REF_SEL(1:0)` and `FB_SEL(1:0)` to select no inputs or test inputs 736a and 736b or ground 738. For a period of time, the LTS will continue to supply a clock and SOS signal to the switch fabric components even though it is receiving no input reference signal.

When ref\_a\_lo and/or ref\_b\_lo are asserted, the LTS hardware control logic notifies its local processor 740 through an interrupt. The SRM will decide, based on a failure policy, what actions to take, including whether to switch over from the master to slave CTS. Just as the phase detector in the CTS sends an out of lock signal to the CTS hardware control logic, the phase detector 722 also sends an out of lock signal OOL to the LTS hardware control logic if the magnitude of the phase difference between the reference and feedback signals exceeds a predetermined threshold. If the LTS hardware receives an asserted OOL signal, it notifies its local processor (e.g., 740) through an interrupt. The SRM will decide based on a failure policy what actions to take.

#### Shared LTS Hardware:

In the embodiment described above, the switch fabric data cards are four independent cards. More data cards may also be used. Alternatively, all of the cross-bar components may be located on one card. As another alternative, half of the cross-bar components may be located on two separate cards and yet attached to the same network device faceplate and share certain components. A network device faceplate is something the network manager can unlatch and pull on to remove cards from the network device. Attaching two switch fabric data cards to the same faceplate effectively makes them one board since they are added to and removed from the network device together. Since they are effectively one board, they may share certain hardware as if all components were on one physical card. In one embodiment, they may share a processor, hardware control logic and activity detectors. This means that these components will be on one of the physical cards but not on the other and signals connected to the two cards allow activity detectors on the one card to monitor the reference and feedback signals on the other card and allow the hardware control logic on the one card to select the inputs for dual MUX 718 on the other card.

#### Scheduler:

Another difficulty with distributing a portion of the switch fabric functionality involves the scheduler component on the switch fabric control cards. In current systems, the entire switch fabric, including all EPP chips, are always present in a network device. Registers

in the scheduler component are configured on power-up or re-boot to indicate how many EPP chips are present in the current network device, and in one embodiment, the scheduler component detects an error and switches over to the redundant switch fabric control card when one of those EPP chips is no longer active. When the EPP chips are distributed to different cards (e.g., forwarding cards) within the network device, an EPP chip may be removed from a running network device when the printed circuit board on which it is located is removed (“hot swap”, “hot removal”) from the network device. To prevent the scheduler chip from detecting the missing EPP chip as an error (e.g., a CRC error) and switching over to the redundant switch fabric control card, prior to the board being removed from the network device, software running on the switch fabric control card re-configures the scheduler chip to disable the scheduler chip’s links to the EPP chip that is being removed.

To accomplish this, a latch 547 (Fig. 40) on the faceplate of each of the printed circuit boards on which a distributed switch fabric is located is connected to a circuit 742 (Fig. 44) also on the printed circuit board that detects when the latch is released. When the latch is released, indicating that the board is going to be removed from the network device, circuit 742 sends a signal to a circuit 743 on both switch fabric control cards indicating that the forwarding card is about to be removed. Circuit 743 sends an interrupt to the local processor (e.g., 710, Fig. 45) on the switch fabric control card. Software (e.g., slave SRM) being executed by the local processor detects the interrupt and sends a notice to software (e.g., master SRM) being executed by the processor (e.g., 24, Fig. 1) on the network device centralized processor card (e.g., 12, Fig. 1, 542 or 543, Fig. 35). The master SRM sends a notice to the slave SRMs being executed by the processors on the switch fabric data cards and forwarding cards to indicate the removal of the forwarding card. The redundant forwarding card switches over to become a replacement for the failed primary forwarding card. The master SRM also sends a notice to the slave SRM on the cross-connection card (e.g., 562-562b, 564a-564b, 566a-566b, 568a-568b, Fig. 35) to re-configure the connections between the port cards (e.g., 554a-554h, 556a-556h, 558a-558h, 560a-560h, Fig. 35) and the redundant forwarding card. The slave SRM on the switch fabric control card re-configures the registers in the scheduler

component to disable the scheduler's links to the EPP chip on the forwarding card that's being removed from the network device. As a result, when the forwarding card is removed, the scheduler will not detect an error due to a missing EPP chip.

Similarly, when a forwarding card is added to the network device, circuit 742 detects the closing of the latch and sends an interrupt to the processor. The slave SRM running on the local processor sends a notice to the Master SRM which then sends a notice to the slave SRMs being executed by the processors on the switch fabric control cards, data cards and forwarding cards indicating the presence of the new forwarding card. The slave SRM on the cross-connection cards may be re-configured, and the slave SRM on the switch fabric control card may re-configure the scheduler chip to establish links with the new EPP chip to allow data to be transferred to the newly added forwarding card.

#### Switch Fabric Control Card Switch-Over:

Typically, the primary and secondary scheduler components receive the same inputs, maintain the same state and generate the same outputs. The EPP chips are connected to both scheduler chips but only respond to the master / primary scheduler chip. If the primary scheduler or control card experiences a failure a switch over is initiated to allow the secondary scheduler to become the primary. When the failed switch fabric control card is re-booted, re-initialized or replaced, it and its scheduler component serve as the secondary switch fabric control card and scheduler component.

In currently available systems, a complex sequence of steps is required to "refresh" or synchronize the state of the newly added scheduler component to the primary scheduler component and for many of these steps, network data transfer through the switch fabric is temporarily stopped (i.e., back pressure). Stopping network data transfer may affect the availability of the network device. When the switch fabric is centralized and all on one board or only a few boards or in its own box, the refresh steps are quickly completed by one or only a few processors limiting the amount of time that network data is not transferred. When the switch fabric includes distributed switch fabric subsystems, the processors that are local to each of the distributed switch fabric subsystems must take part

in the series of steps. This may increase the amount of time that data transfer is stopped further affecting network device availability.

To limit the amount of time that data transfer is stopped in a network device including distributed switch fabric subsystems, the local processors each set up for a refresh while data is still being transferred. Communications between the processors take place over the Ethernet bus (e.g., 32, Fig. 1, 544, Fig. 35) to avoid interrupting network data transfer. When all processors have indicated (over the Ethernet bus) that they are ready for the refresh, the processor on the master switch fabric control card stops data transfer and sends a refresh command to each of the processors on the forwarding cards and switch fabric cards. Since all processors are waiting to complete the refresh, it is quickly completed. Each processor notifies the processor on the master switch fabric control card that the refresh is complete, and when all processors have completed the refresh, the master switch fabric control card re-starts the data transfer.

During the time in which the data transfer is stopped, the buffers in the traffic management chips are used to store data coming from external network devices. It is important that the data transfer be complete quickly to avoid overrunning the traffic management chip buffers.

Since the switch over of the switch fabric control cards is very complex and requires that data transfer be stopped, even if briefly, it is important that the CTSs on each switch fabric control card be independent of the switch fabric functionality. This independence allows the master CTS to switch over to the slave CTS quickly and without interrupting the switch fabric functionality or data transmission.

As described above, locating the EPP chips and data slice chips of the switch fabric subsystem on the forwarding cards is difficult and against the teachings of a manufacturer of these components. However, locating these components on the forwarding cards allows the base network device – that is, the minimal configuration – to include only a necessary portion of the switching fabric reducing the cost of a minimally configured

network device. As additional forwarding cards are added to the minimal configuration - to track an increase in customer demand -- additional portions of the switch fabric are simultaneously added since a portion of the switch fabric is located on each forwarding card. Consequently, switch fabric growth tracks the growth in customer demands and fees. Also, typical network devices include 1:1 redundant switch fabric subsystems. However, as previously mentioned, the forwarding cards may be 1:N redundant and, thus, the distributed switch fabric on each forwarding card is also 1:N redundant further reducing the cost of a minimally configured network device.

#### External Network Data Transfer Timing:

In addition to internal switch fabric timing, a network device must also include external network data transfer timing to allow the network device to transfer network data synchronously with other network devices. Generally, multiple network devices in the same service provider site synchronize themselves to Building Integrated Timing Supply (BITS) lines provided by a network service provider. BITS lines are typically from highly accurate stratum two clock sources. In the United States, standard T1 BITS lines (2.048 MHz) are provided, and in Europe, standard E1 BITS lines (1.544 MHz) are provided. Typically, a network service provider provides two T1 lines or two E1 lines from different sources for redundancy. Alternatively, if there are no BITS lines or when network devices in different sites want to synchronously transfer data, one network device may extract a timing signal received on a port connected to the other network device and use that timing signal to synchronize its data transfers with the other network device.

Referring to Fig. 49, controller card 542b and redundant controller card 543b each include an external central timing subsystem (EX CTS) 750. Each EX CTS receives BITS lines 751 and provide BITS lines 752. In addition, each EX CTS receives a port timing signal 753 from each port card (554a-554h, 556a-556h, 558a-558h, 560a-560h, Fig. 35), and each EX CTS also receives an external timing reference signal 754 from itself and an external timing reference signal 755 from the other EX CTS.









MSTM-S3 available from Conner-Winfield or an ATIMe-s or ATIMe-3E available from TF systems. The hardware control logic, activity detectors and dual MUXs may be implemented in an FPGA. The timing module also includes a Free-run mode and a Hold-Over mode. When there is no input signal to synchronize to, the timing module enter a free-run mode and uses the internal oscillator to generate a clock output signal. If the signal being synchronized to is lost, then the timing module enters a hold-over mode and maintains the frequency of the last known clock output signal for a period of time.

The EX CTS 750 also receives an external timing reference signal from the other EX CTS on STRAT\_SYNC 755 (one of STRAT\_REF1-STRAT\_REFN from the other EX CTS). STRAT\_SYNC and output 770 from the timing module are sent to a MUX 772a. REF\_SEL(1:0) selection signals are sent from the hardware control logic to MUX 772a to select STRAT\_SYNC when the EX CTS is the slave and output 770 when the EX CTS is the master. When in a test mode, the hardware control logic may also select a test input from a test header 771a.

An activity detector 774a monitors the status of output 770 from the timing module and provides a status signal to the hardware control logic. Similarly, an activity detector 774b monitors the status of STRAT\_SYNC and provides a status signal to the hardware control logic. When the EX CTS is master, if the hardware control logic receives an inactive status from activity detector 774a, then the hardware control logic automatically changes the REF\_SEL signals to select STRAT\_SYNC forcing the EX CTS to switch over and become the slave. When the EX CTS is slave, if the hardware control logic receives an inactive status from activity detector 774b, then the hardware control logic may automatically change the REF\_SEL signals to select output 770 from the timing module forcing the EX CTS to switch over and become master.

A MUX 772b receives feedback signals from the EX CTS itself. BENCH\_FB is an external timing reference signal from the EX CTS that is routed back to the MUX on the local printed circuit board. STRAT\_FB 754 is an external timing reference signal from the EX CTS (one of STRAT\_REF1-STRAT\_REFN) that is routed onto the mid-plane(s)

and back onto the local printed circuit board such that is most closely resembles the external timing reference signals sent to the EX LTSs and the other EX CTS in order to minimize skew. The hardware control logic sends FB\_SEL(1:0) signals to MUX 772b to select STRAT\_FB in regular use or BENCH\_FB or an input from a test header 771b in test mode.

The outputs of both MUX 772a and 772b are provided to a phase detector 776. The phase detector compares the rising edge of the two input signals to determine the magnitude of any phase shift between the two. The phase detector then generates variable voltage pulses on outputs 777a and 777b representing the magnitude of the phase shift. The phase detector outputs are used by discrete logic circuit 778 to generate a voltage on signal 779 representing the magnitude of the phase shift. The voltage is used to speed up or slow down (i.e., change the phase of) a VCXO 780 to allow the output signal 781 to track any phase change in the external timing reference signal received from the other EX CTS (i.e., STRAT\_SYNC) or to allow the output signal 781 to track any phase change in the output signal 770 from the timing module. The discrete logic components implement a filter that determines how quickly or slowly the VCXO's output tracks the change in phase detected on the reference signal.

The phase detector circuit may be implemented in a programmable logic device (PLD).

The output 781 of the VCXO is sent to an External Reference Clock (ERC) circuit 782 which may also be implemented in a PLD. ERC\_STRAT\_SYNC is also sent to ERC 782 from the output of MUX 772a. When the EX CTS is the master, the ERC circuit generates the external timing reference signal 784 with an embedded processor timing reference signal, as described below, based on the output signal 781 and synchronous with ERC\_STRAT\_SYNC (corresponding to timing module output 770). When the EX CTS is the slave, the ERC generates the external timing reference signal 784 based on the output signal 781 and synchronous with ERC\_STRAT\_SYNC (corresponding to STRAT\_SYNC 755 from the other EX CTS).











A second MUX 810b receives a feed back signal 816 from the EX LTS itself. Hardware control logic 812 uses FB\_SEL(1:0) to select either a feedback signal input to MUX 810b or a test header 818b input to MUX 810b. The test header input is only used in a test mode. In regular use, feedback signal 816 is selected. Similarly, in a test mode, the hardware control logic may use REF\_SEL(1:0) to select a test header 818a input to MUX 810a.

Output signals 820a and 820b from MUXs 810a and 810b, respectively, are provided to phase detector 822. The phase detector compares the rising edge of the two input signals to determine the magnitude of any phase shift between the two. The phase detector then generates variable voltage pulses on outputs 821a and 821b representing the magnitude of the phase shift. The phase detector outputs are used by discrete logic circuit 822 to generate a voltage on signal 823 representing the magnitude of the phase shift. The voltage is used to speed up or slow down (i.e., change the phase of) of an output 825 of a VCXO 824 to track any phase change in STRAT\_REF\_A or STRAT\_REF\_B. The discrete logic components implement filters that determine how quickly or slowly the VCXO's output will track the change in phase detected on the reference signal.

In one embodiment, the VCXO is a 155.51MHz or a 622MHz VCXO. This value is dependent upon the clock speeds required by components, outside the EX LTS but on the local card, that are responsible for transferring network data over the optical fibers in accordance with the SONET protocol. On at least the universal port card, the VCXO output 825 signal is sent to a clock driver 830 for providing local data transfer components with a 622MHz or 155.52MHz clock signal 831.

The VCXO output 825 is also sent to a divider chip 826 for dividing the signal down and outputting a 77.76MHz output signal 827 to a clock driver chip 828. Clock driver chip 828 provides 77.76MHz output signals 829a for use by components on the local printed circuit board and provides 77.76MHz output signal 829b to ERC circuit 782. The ERC circuit also receives input signal 832 corresponding to the EX LTS selected input signal either STRAT REF B or STRAT REF A. As shown, the same ERC circuit that is used



received as input 838 (marked “Alt. Input from other EX CTS”). The PLL circuit, including MUXs 772a and 772b, phase detector 776, discrete logic circuit 778 and VCXO 780, is necessary to synchronize the output of the VCXO with either output 770 of the timing module or a signal from the other EX CTS. However, PLL circuits may introduce jitter into their output signals (e.g., output 781), and passing the PLL output signal 781 via one of the STRAT\_REF1-STRAT\_REFN signals from one EX CTS into the PLL of the other EX CTS – that is, PLL to PLL -- may introduce additional jitter into output signal 781. Since accurate timing signals are critical for proper data transfer with other network devices and SONET standards specifically set maximum allowable jitter transmission at interfaces (Bellcore GR-253-CORE and SONET Transport Systems Common Carrier Criteria), jitter should be minimized. Passing the output 770 of the timing module within the EX CTS to the input 838 of the other EX CTS avoids passing the output of one PLL to the input of the second PLL and thereby reduces the potential introduction of jitter.

It is still necessary to send one of the STRAT\_REF1-STRAT\_REFN signals to the other EX CTS (received as STRAT\_SYNC 755) in order to provide ERC 782 with a 19.44MHz signal with an embedded 8KHz clock for use when the EX CTS is a slave. The ERC circuit only uses ERC\_STRAT\_SYNC in this instance when the EX CTS is the slave.

Layer One Test Port:

The present invention provides programmable physical layer (i.e., layer one) test ports within an upper layer network device (e.g., network device 540, Fig. 35). The test ports may be connected to external test equipment (e.g., an analyzer) to passively monitor data being received by and transmitted from the network device or to actively drive data to the network device. Importantly, data provided at a test port accurately reflects data received by or transmitted by the network device with minimal modification and no upper layer translation or processing. Moreover, data is supplied to the test ports without disrupting or slowing the service provided by the network device.

Referring to Figs. 35 and 36, network device 540 includes at least one cross-connection card 562a-562b, 564a-564b, 566a-566b, 568a-568b, at least one universal port card 554a-554h, 556a-556h, 558a-558h, 560a-560h, and at least one forwarding card 546a-546e, 548a-548e, 550a-550e, 552a-552e. Each port card includes at least one port 571a-571n for connecting to external physical network attachments 576a-576b, and each port card transfers data to a cross-connection card. The cross-connection card transfers data between port cards and forwarding cards and between port cards. In one embodiment, each forwarding card includes at least one port/payload extractor 582a-582n for receiving data from the cross-connection cards.

Referring to Fig. 56, a port 571a on a port card 554a within network device 540 may be connected to another network device (not shown) through physical external network attachments 576a and 576b. As described above, components 573 on the port card transfer data between port 571a and cross-connection card 562a, and components 563 on the cross-connection card transfer data on particular paths between the port cards and the forwarding cards or between port cards. For convenience, only one port card, forwarding card and cross-connection card are shown.

For many reasons, including error diagnosis, a service administrator may wish to monitor the data received on a particular path or paths at a particular port, for example, port 571a, and/or the data transmitted on a particular path or paths from port 571a. To accomplish this, the network administrator may connect test equipment, for example, an analyzer 840 (e.g., an Omniber analyzer available from Hewlett Packard Company), to the transmit connection of port 571b to monitor data received at port 571a and/or to the transmit connection of port 571c to monitor data transmitted from port 571a. The network administrator then notifies the NMS (e.g., NMS 60 running on PC 62, Fig. 35) as to which port or ports on which port card or port cards should be enabled and whether the transmitter and/or receiver for each port should be enabled. The network administrator also notifies the NMS as to which path or paths are to be sent to each test port, and the time slot for each path. With this information, the NMS fills in test path table 841 (Figs. 57 and 58) in configuration database 42.



corresponding to path LID 1666 and received on port 571a to port 571b and data corresponding to path LID 1666 and transmitted to port 571a by forwarding card 546c to port 571c.

Instead of passively monitoring the data received at port 571a, test equipment 840 may be connected to the receiver of a test port and used to drive data to network device 540. For example, the network administrator may connect test equipment 840 to the receiver of test port 571c and then notify the NMS to enable the receiver on port 571c to receive path 1666. With this information, the NMS modifies test path table 841. For example, record 844 (Fig. 58) indicates that the receive portion of path 1666 (i.e., "ingress" in Monitor column 844) is to be driven (i.e., "yes" in Enable Port Receiver column 845) externally with data from port LID 1233 (i.e., port 571c). Again, an active query notification is sent to path manager 597. Path manager 597 then disables the receiver corresponding to port LID 1231 (i.e., port 571a) and enables the receiver corresponding to port LID 1233 (i.e., port 571c) and passes the path connection information to cross-connection manager 605 indicating that port LID 1231 will supply the receive portion of path 1666. The cross-connection manager uses the connection information to generate a new connection program table 601 to re-program the internal connections through the cross-connection card. In addition, the network administrator may also indicate that the transmitter of port 571a should be disabled, and path manager 597 would disable the transmitter of port 571a and pass the connection information to the cross connection manager.

After re-programming, cross-connection card 562a data is sent from test equipment 840 to test port 571c and then through the cross-connection card to forwarding card 546c. The cross-connection card may multicast the data from forwarding card 546c to both working port 571a and to test port 571c, or just to test port 571c or just working port 571a.

Instead of having test equipment 840 drive data to the network device over a test port, internal components on a port card, cross-connection card or forwarding card within the network device may drive data to the other cards and to other network devices over external physical attachments connected to working ports and/or test ports. For example, the internal components may be capable of generating a pseudo-random bit sequence (PRBS). Test equipment 840 connected to one or more test ports may then be used to

passively monitor the data sent from and/or received by the working port, and the internal components may be capable of detecting a PRBS over the working port and/or test port(s).

Although the test ports have been shown on the same port card as the working port being tested, it should be understood, that the test ports may be on any port card in the same quadrant as the working port. Where cross-connection cards are interconnected, the test ports may be on any port card in a different quadrant so long as the cross-connection card in the different quadrant is connected to the cross-connection card in same quadrant as the working port. Similarly, the test ports may be located on different port cards with respect to each other. A different working port may be tested by re-programming the cross-connection card to multicast data corresponding to the different working port to the test port(s). In addition, multiple working ports may be tested simultaneously by re-programming the cross-connection card to multicast data from different paths on different working ports to the same test port(s) or to multiple different test ports. A network administrator may choose to dedicate certain ports as test ports prior to any testing needing to be done or the network administrator may choose certain ports as test ports when problems arise.

The programmable physical layer test port or ports allow a network administrator to test data received at or transmitted from any working port or ports and also to drive data to any upper layer card (i.e., forwarding card) within the network device. Only the port card(s) and cross-connection card need be working properly to passively monitor data received at and sent from a working port. Testing and re-programming test ports may take place during normal operation without disrupting data transfer through the network device to allow for diagnosis without network device disruption.

It will be understood that variations and modifications of the above described methods and apparatuses will be apparent to those of ordinary skill in the art and may be made without departing from the inventive concepts described herein. Accordingly, the



embodiments described herein are to be viewed merely as illustrative, and not limiting, and the inventions are to be limited solely by the scope and spirit of the appended claims.

US 2013/0198100 A1

Claims:

1. A method of managing a telecommunications network, comprising:  
presenting a graphical user interface (GUI) to a user, including:  
    providing a plurality of screen marks; and  
    jumping to a GUI screen corresponding to a first one of the plurality of screen marks  
in response to the user's selection of the first screen mark.
2. The method of claim 1, further comprising:  
    jumping to a GUI screen corresponding to a second one of the plurality of screen  
marks in response to the user's selection of the second screen mark.
3. The method of claim 1, wherein providing a plurality of screen marks comprises:  
    displaying the screen marks in a pull-down menu.
4. The method of claim 1, wherein at least one of the screen marks comprises a default  
screen mark.
5. The method of claim 1, wherein at least one of the screen marks comprises a custom  
screen mark.
6. A network management system, comprising:  
    a graphical user interface (GUI) including a custom navigator tool.
7. The network management system of claim 6, wherein the GUI further includes:  
    a plurality of screen marks.
8. The network management system of claim 7, wherein the plurality of screen marks  
includes:  
    at least one default screen mark.

9. The network management system of claim 7, wherein the plurality of screen marks includes:  
at least one custom screen mark.
10. A method of managing a telecommunications network, comprising:  
displaying a graphical user interface (GUI) screen in response to input from a user;  
receiving a screen mark selection from the user; and  
creating a custom screen mark in response to the screen mark selection.
11. The method of claim 7, wherein after receiving a screen mark selection from the user, the method further comprises:  
prompting the user to input a screen mark name;  
receiving a screen mark name from the user; and  
wherein creating a custom screen mark in response to the screen mark selection includes:  
naming the custom screen mark with the screen mark name received from the user.
12. The method of claim 7, further comprising:  
displaying the custom screen mark.
13. The method of claim 9, wherein displaying the custom screen mark comprises:  
listing the custom screen mark in a pull down menu.
14. The method of claim 10, wherein the pull down menu further lists other screen marks.
15. The method of claim 11, wherein the other screen marks include at least one default screen mark.
16. The method of claim 7, further comprising:  
detecting a selection of the custom screen mark by the user; and

### **Abstract of the Disclosure**

To simplify network device configuration tasks and provide configuration flexibility and efficiency, the present invention includes a custom navigator tool. Through the custom navigator tool, a network manager may select various screen marks each of which causes the custom navigator tool to shortcut the configuration process by jumping forward past various configuration screens to a particular configuration screen corresponding to the screen mark. The screen marks may be default screen marks provided as a standard part of a network management system graphical user interface (GUI) and/or the screen marks may be custom screen marks created by the network manager. To create a custom screen mark the network manager simply accesses a desired GUI screen and selects a screen mark option. The custom navigator tool then requests a screen mark name from the network manager and, once provided, lists the custom screen mark name in an inventory of available screen mark names. When the network manager selects a screen mark name (custom or default), the custom navigator tool jumps to the corresponding GUI screen. As a result, the custom navigator tool allows a network manager to customize the GUI and, thus, make their provisioning tasks more efficient. The screen marks provide configuration short cuts that may simplify the configuration process and save the administrator configuration time.

FIG. 1

10

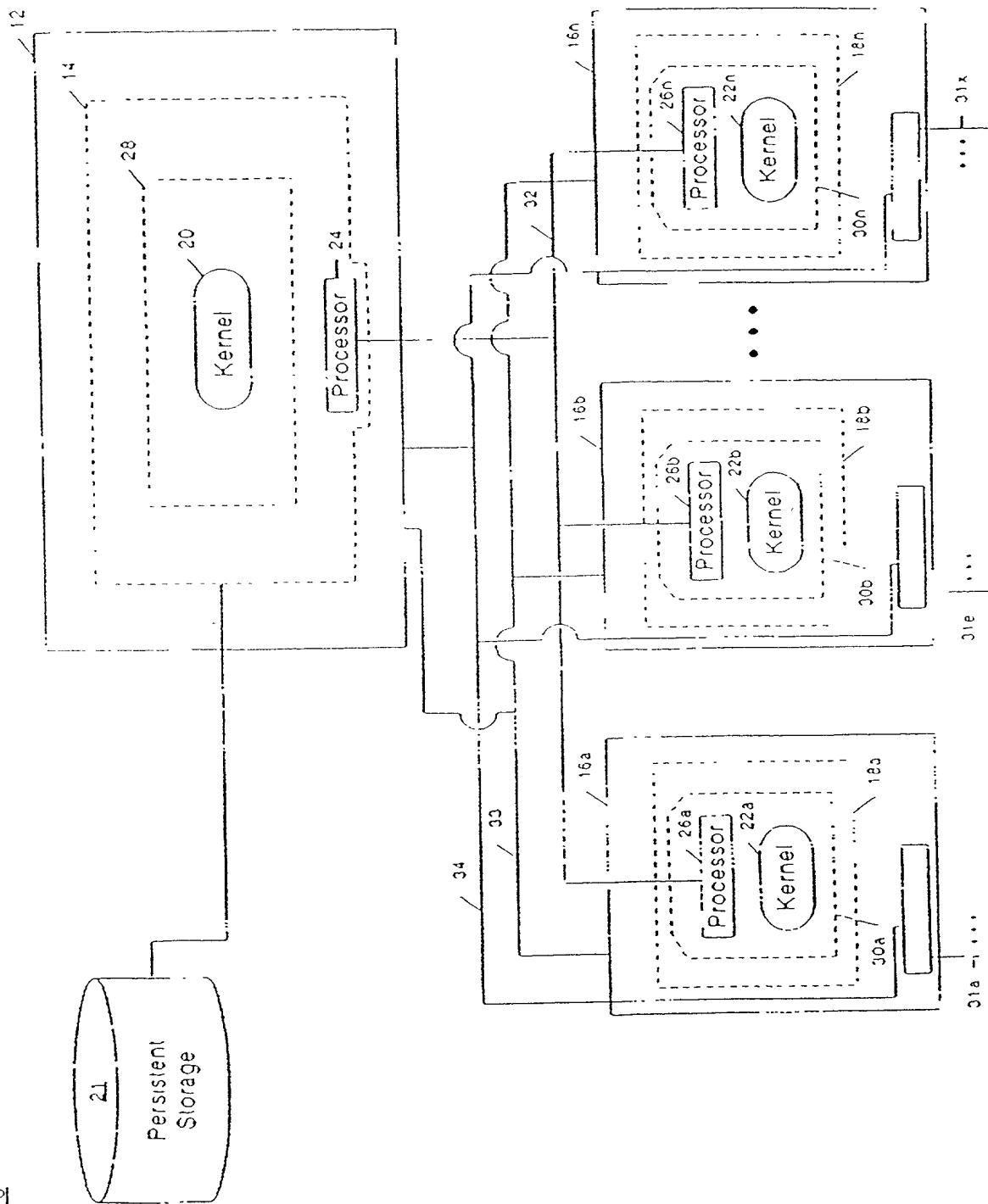
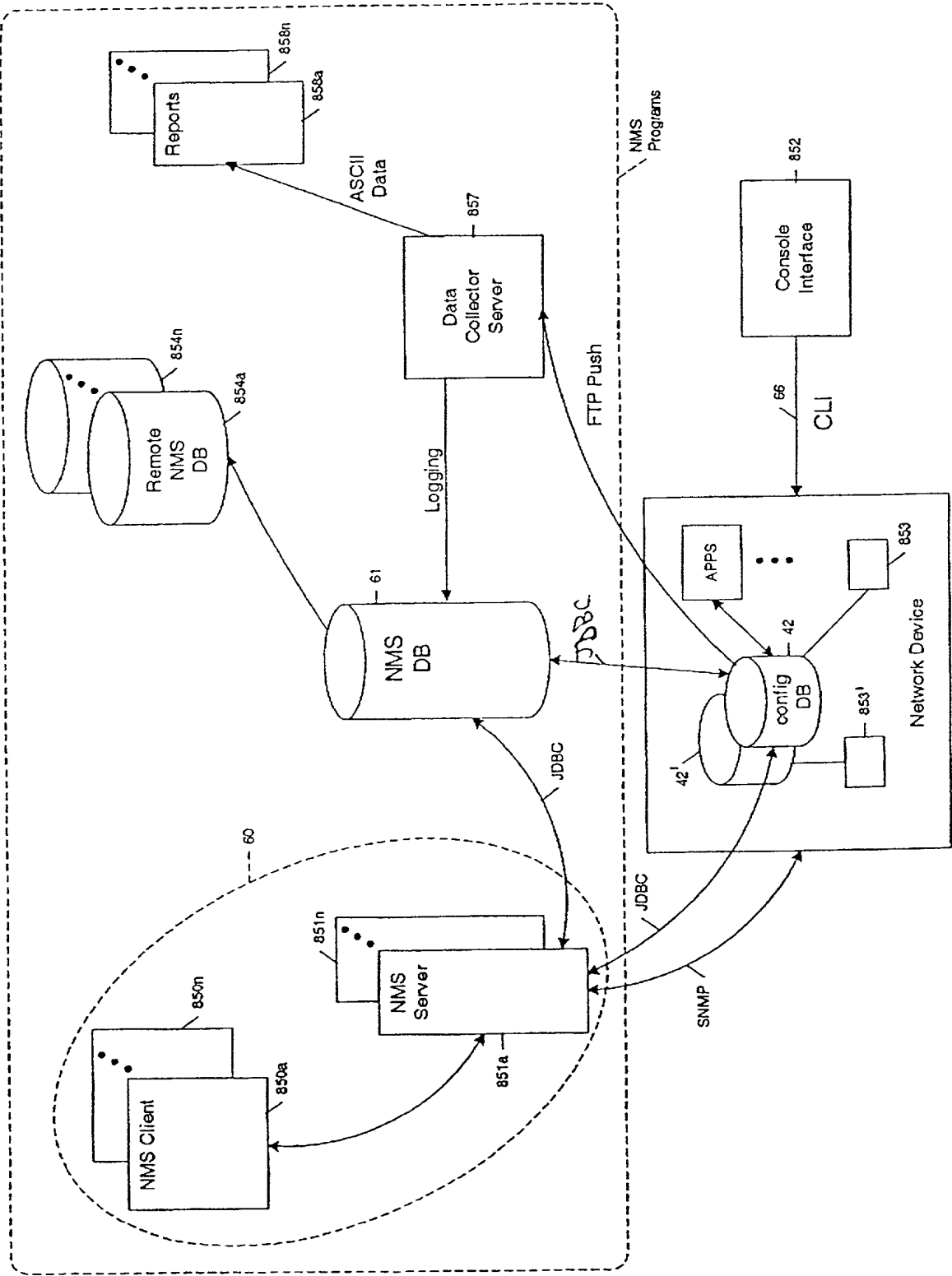
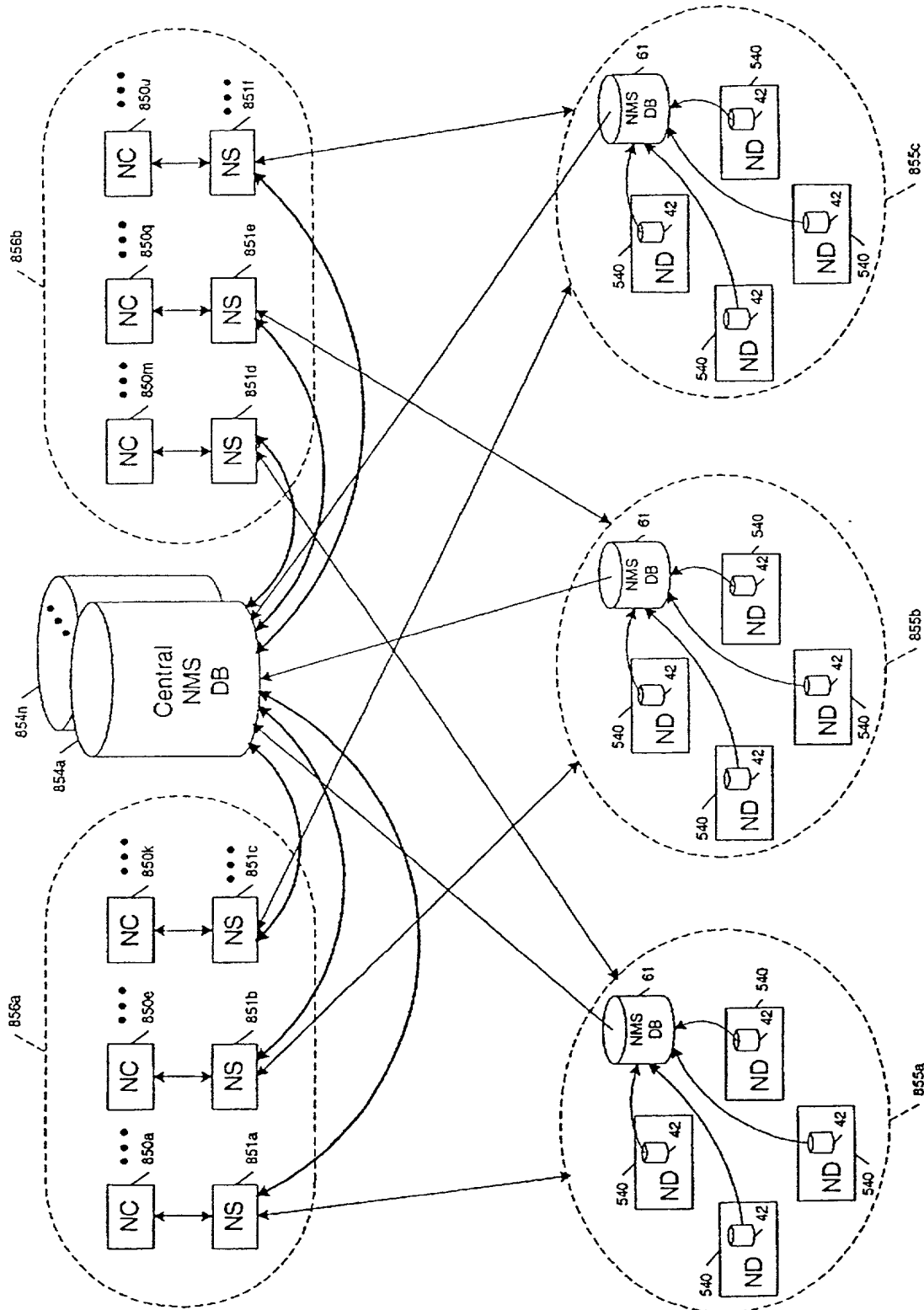


Fig. 2a



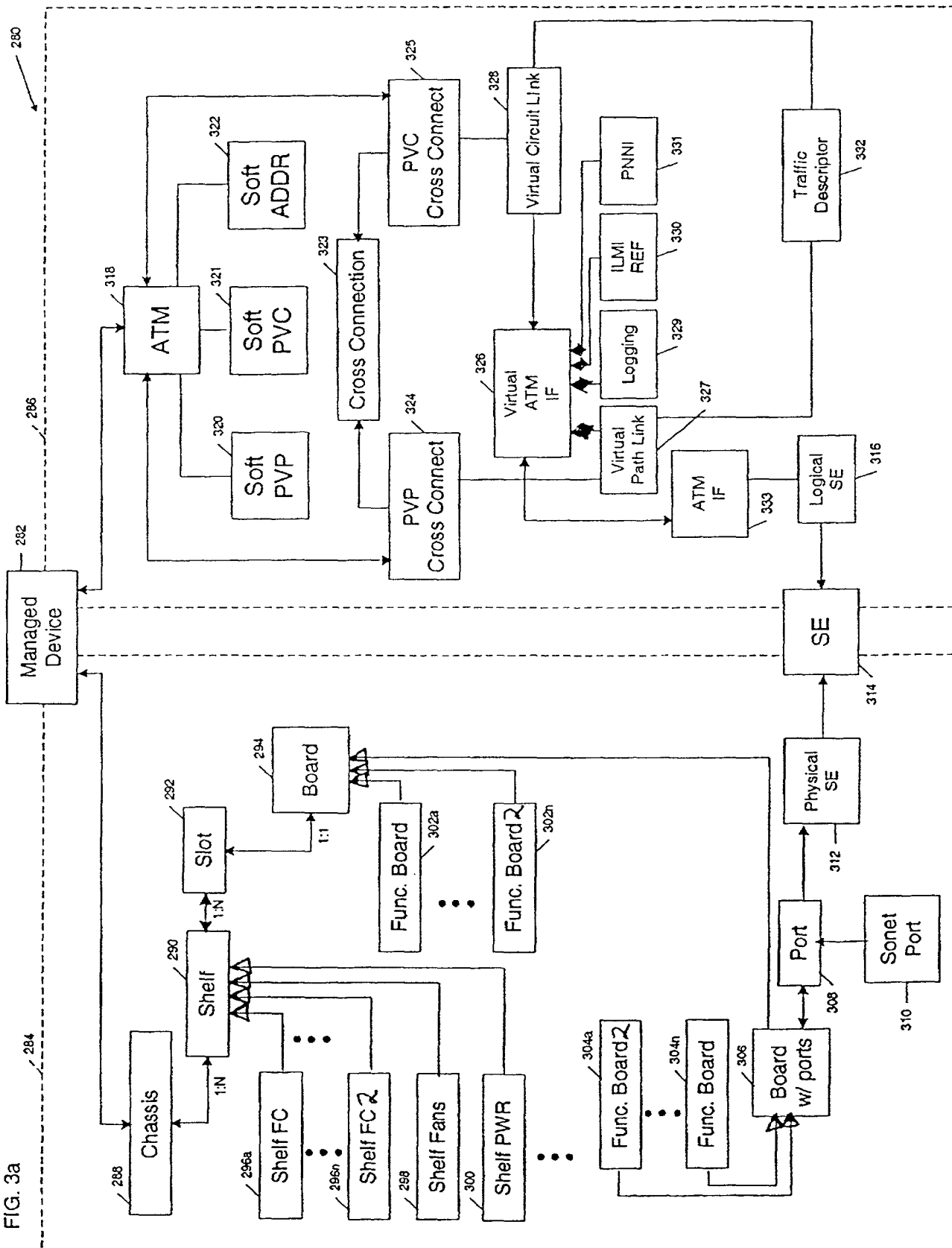
NOTED AT 67550

Fig. 2b



OFFER SET 2500

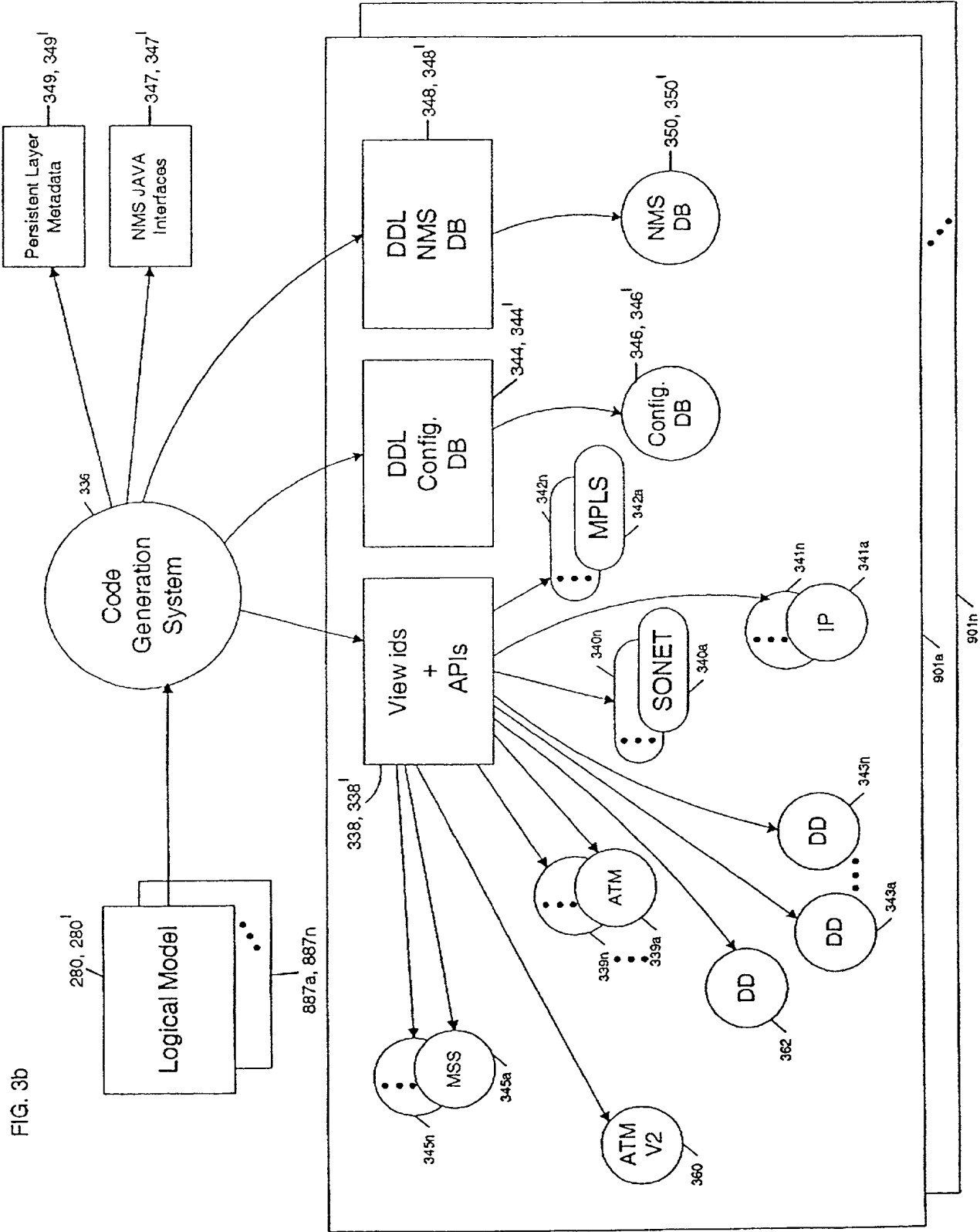
FIG. 3a





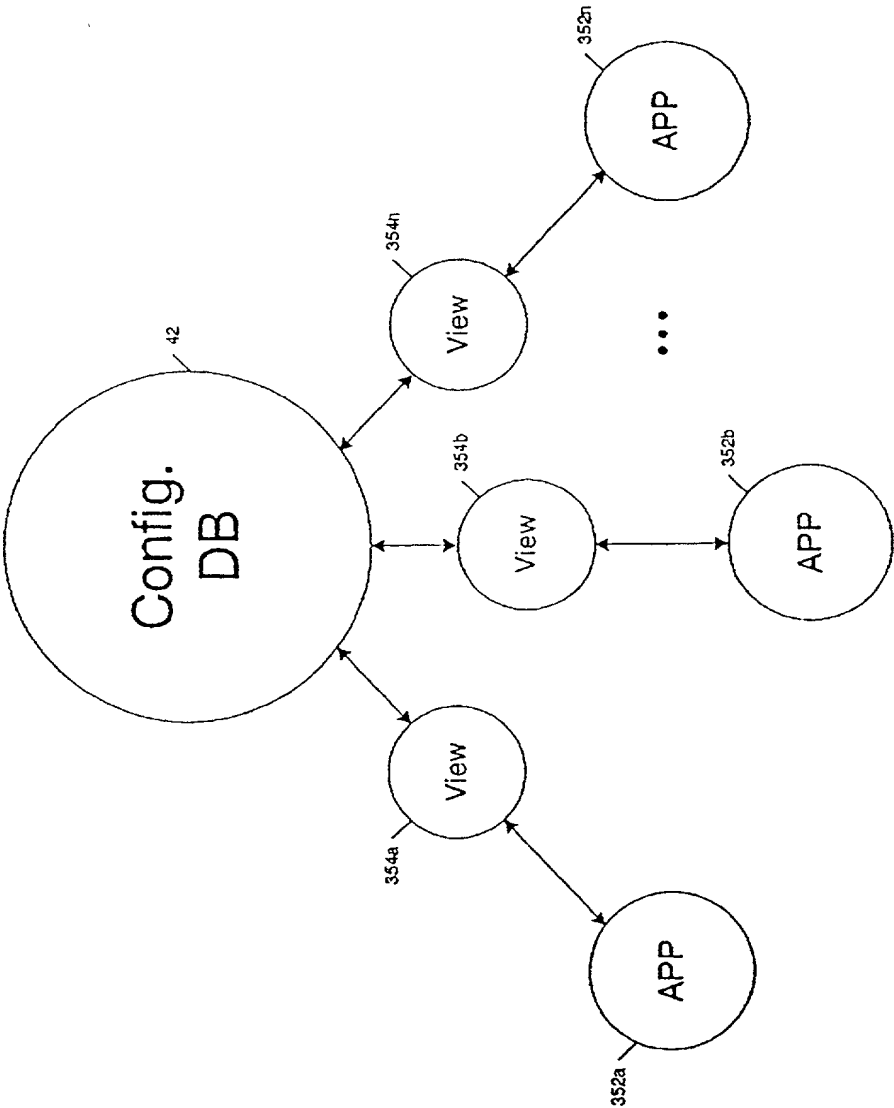
DATE: 07/21/2000

FIG. 3b



noted" at 5:50

FIG. 3c



OUTSIDE THE SONET

Fig. 3d

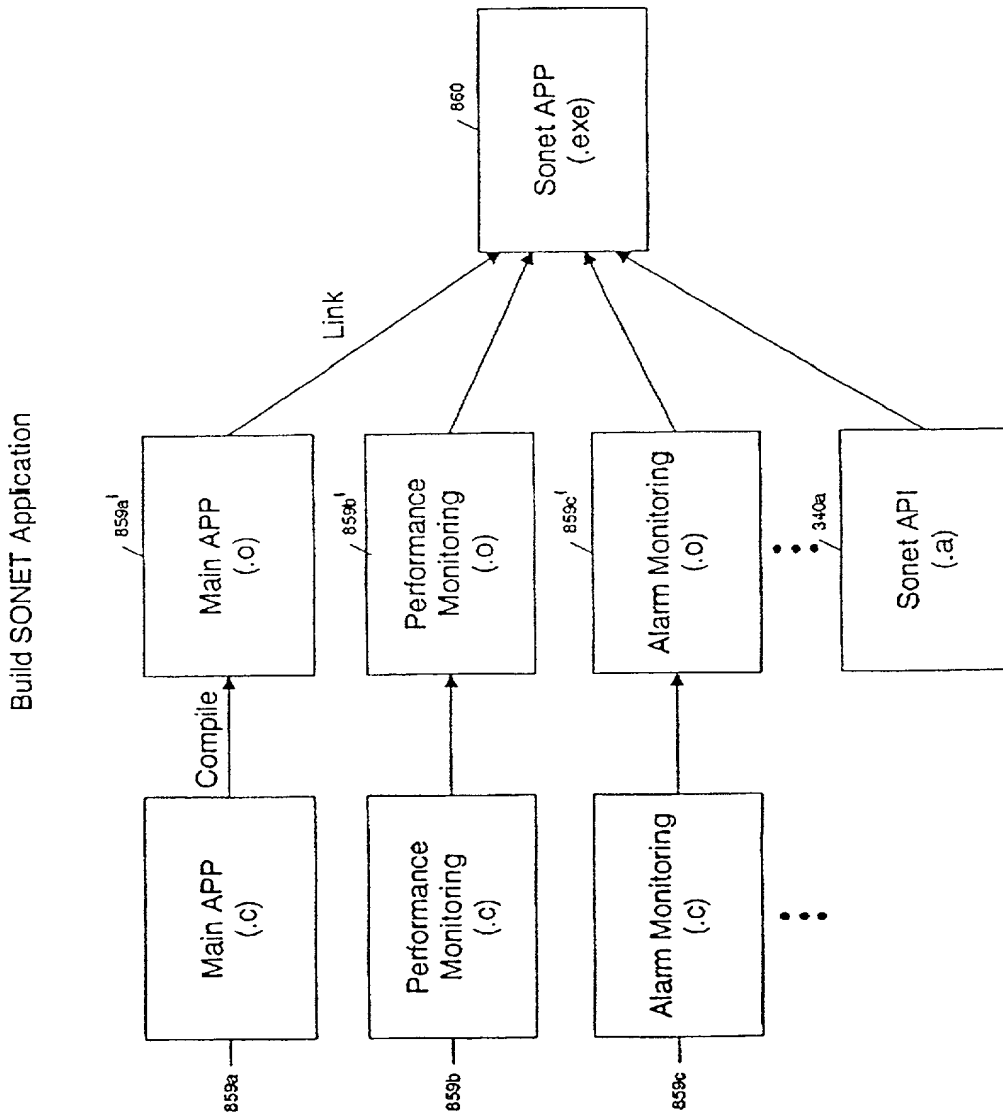
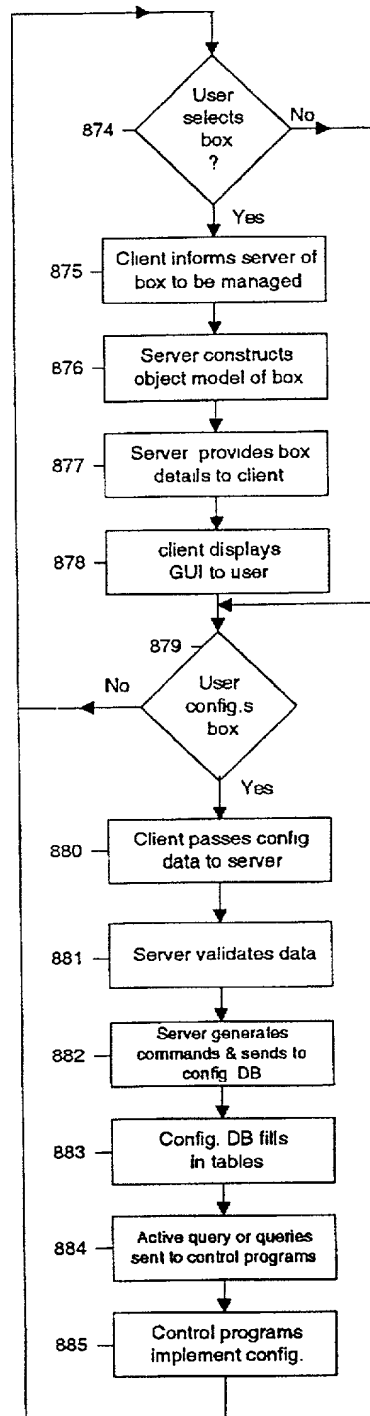






Fig. 3g





```

Command Prompt (2) - enetcli
Enetcli>
Enetcli>
Enetcli>
Enetcli>
Enetcli>
Enetcli>
Enetcli>
Enetcli>
Enetcli>
912 Enetcli>
Enetcli>
Enetcli>
Enetcli> help
Commands are:
bye
close
execute
help
load
manage
open
quit
showCurrent
showTemplate
set
status
writeCurrent
writeTemplate
Enetcli>
Enetcli>
914 Enetcli> showCurrent SPATH
ATMIfName=ATMIf11/1/1
Concatenated=false
Name=Path11/1/1
Operant=SPATH
Operator=Create
PortID=1
Position=1
Service=ATM
ShelfID=11
SlotID=1
Type=Terminated
Version=V1_1_0_0
Width=STS3
Enetcli>
Enetcli>
Enetcli>
916 Enetcli> showTemplate SPATH
ATMIfName=<String>[TerminatedOnly]
Concatenated=<true|false>
Name=<String>
Operant=SPATH
Operator=<Create|Replace|Update|Delete>
PortID=<Integer><1-16>
Position=<Integer>
Service=<None|ATM>
ShelfID=<11|top|13|bottom>
SlotID=<Integer><1-8>
Type=<Switched|Terminated>
Version=V1_1_0_0
Width=<STS1|STS3|STS12|STS48>
Enetcli>
Enetcli>
918 Enetcli> status
919 Not currently connected to server
Supporting templates: CONTROL, PUC, SPATH, SPUC, ID, and UAIF
920 Enetcli>

```

Fig.3i



Fig. 3j

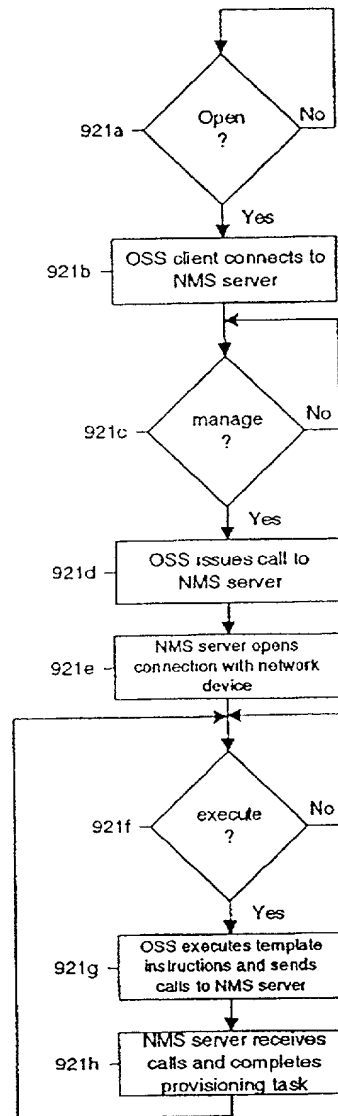


Fig. 3K

```

922 Enetcli>
Enetcli> showCurrent CONTROL
Input=Q:\nms\com\equipecon\nms\utils\enetcli
Interactive=false
Operand=CONTROL
923d Operator=Manage
923f Output=Q:\nms\com\equipecon\nms\utils\enetcli
923c Password=None
923e System=192.168.9.202
923b User=None
923b Version=U1_1_0_0
923g Server=localhost
923a Enetcli>

```

Variable	Mean	SD	Min	Max
Age	34.5	10.2	22	55
Gender	0.5	0.5	0	1
Marital status	0.6	0.5	0	1
Education	12.5	1.5	10	15
Income	1500	500	1000	2500
Health status	0.8	0.2	0	1
Smoking status	0.3	0.5	0	1
Alcohol consumption	0.2	0.4	0	1
Exercise frequency	0.5	0.5	0	1
Stress level	0.7	0.3	0	1
Depression score	0.4	0.4	0	1
Life satisfaction	0.6	0.3	0	1
Quality of life	0.7	0.2	0	1
Healthcare utilization	0.5	0.5	0	1
Health insurance	0.9	0.1	0	1
Healthcare access	0.8	0.2	0	1
Healthcare cost	0.6	0.3	0	1
Healthcare quality	0.7	0.2	0	1
Healthcare satisfaction	0.8	0.2	0	1
Healthcare equity	0.7	0.2	0	1
Healthcare efficiency	0.6	0.3	0	1
Healthcare effectiveness	0.7	0.2	0	1
Healthcare safety	0.8	0.2	0	1
Healthcare transparency	0.7	0.2	0	1
Healthcare accountability	0.6	0.3	0	1
Healthcare responsibility	0.7	0.2	0	1
Healthcare integrity	0.8	0.2	0	1
Healthcare honesty	0.7	0.2	0	1
Healthcare fairness	0.6	0.3	0	1
Healthcare justice	0.7	0.2	0	1
Healthcare freedom	0.8	0.2	0	1
Healthcare security	0.7	0.2	0	1
Healthcare stability	0.6	0.3	0	1
Healthcare sustainability	0.7	0.2	0	1
Healthcare resilience	0.8	0.2	0	1
Healthcare adaptability	0.7	0.2	0	1
Healthcare innovation	0.6	0.3	0	1
Healthcare leadership	0.7	0.2	0	1
Healthcare vision	0.8	0.2	0	1
Healthcare mission	0.7	0.2	0	1
Healthcare values	0.6	0.3	0	1
Healthcare culture	0.7	0.2	0	1
Healthcare climate	0.8	0.2	0	1
Healthcare environment	0.7	0.2	0	1
Healthcare system	0.6	0.3	0	1
Healthcare organization	0.7	0.2	0	1
Healthcare structure	0.8	0.2	0	1
Healthcare process	0.7	0.2	0	1
Healthcare outcome	0.6	0.3	0	1
Healthcare impact	0.7	0.2	0	1
Healthcare contribution	0.8	0.2	0	1
Healthcare legacy	0.7	0.2	0	1
Healthcare reputation	0.6	0.3	0	1
Healthcare brand	0.7	0.2	0	1
Healthcare identity	0.8	0.2	0	1
Healthcare image	0.7	0.2	0	1
Healthcare perception	0.6	0.3	0	1
Healthcare attitude	0.7	0.2	0	1
Healthcare behavior	0.8	0.2	0	1
Healthcare belief	0.7	0.2	0	1
Healthcare opinion	0.6	0.3	0	1
Healthcare view	0.7	0.2	0	1
Healthcare understanding	0.8	0.2	0	1
Healthcare knowledge	0.7	0.2	0	1
Healthcare skill	0.6	0.3	0	1
Healthcare ability	0.7	0.2	0	1
Healthcare talent	0.8	0.2	0	1
Healthcare potential	0.7	0.2	0	1
Healthcare strength	0.6	0.3	0	1
Healthcare power	0.7	0.2	0	1
Healthcare influence	0.8	0.2	0	1
Healthcare authority	0.7	0.2	0	1
Healthcare expertise	0.6	0.3	0	1
Healthcare competence	0.7	0.2	0	1
Healthcare proficiency	0.8	0.2	0	1
Healthcare mastery	0.7	0.2	0	1
Healthcare excellence	0.6	0.3	0	1
Healthcare achievement	0.7	0.2	0	1
Healthcare success	0.8	0.2	0	1
Healthcare fulfillment	0.7	0.2	0	1
Healthcare happiness	0.6	0.3	0	1
Healthcare joy	0.7	0.2	0	1
Healthcare love	0.8	0.2	0	1
Healthcare compassion	0.7	0.2	0	1

Fig. 3L

← 924 BATCH

Operant=BATCH

Operator=Execute

Version=V1\_1\_0\_0

924a — Task1=execute-SPATH

924b — Task2=execute-PVC

924c — Task3=execute-SPVC

924d — Task4=load-SPVC-spvc1

924e — Task5=execute-SPVC

924f — Task6=load-SPVC-spvc2

924g — Task7=execute-SPVC

.

.

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924h — Task50=set-SPATH-PortID-3

924i — Task51=execute-SPATH

924j — Task52=set-SPATH-SlotID-2

924k — Task53=execute-SPATH

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Fig. 3M

← 925

Operant=BATCH

Operator=Execute

- Version=VI\_1\_0\_0

925a — Task1=execute-CONTROL

925b — Task2=execute-SPATH

925c — Task3=set-SPATH-PortID-3

925d — Task4=execute-SPATH

925e — Task61=set-CONTROL-System-192.168.9.201

925f — Task62=execute-CONTROL

925g — Task63=execute-SPATH

925h — Task108=close

925i — Task109=set-CONTROL-Server-Server1

925j — Task110=set-CONTROL-System-192.168.8.200

925k — Task111=execute-CONTROL

925l — Task112=execute-SPATH

925m

925n

925o

925p

925q

925r

925s

925t

925u

925v

925w

925x

925y

925z

925aa

925ab

925ac

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925ak

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925aq

925ar

925as

925at

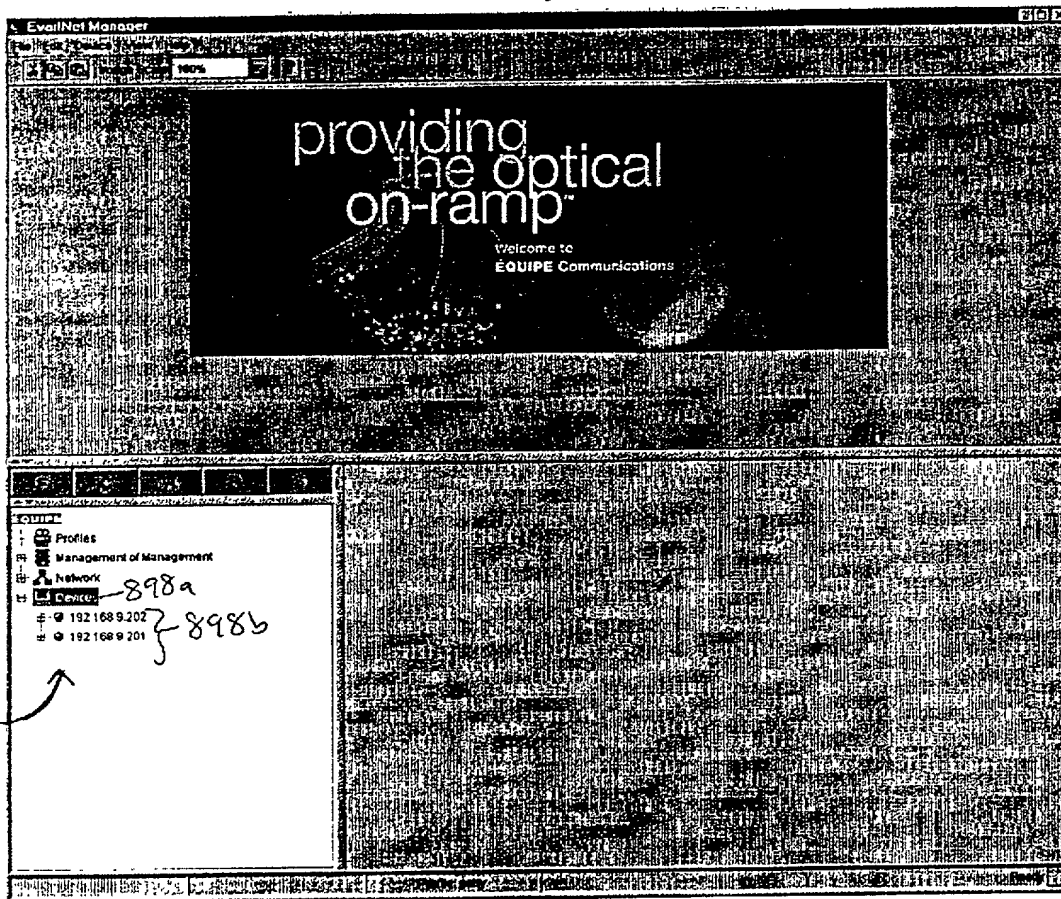


Fig. 4a

Table 1	
Summary of the study	
Study design	Retrospective cohort study
Study period	1990-1999
Study location	United States
Study population	1,000,000
Study variables	Age, sex, race, education, income, occupation, health status, lifestyle factors, environmental factors, social factors, genetic factors, clinical factors, laboratory factors, imaging factors, treatment factors, outcome factors
Study results	See text for details

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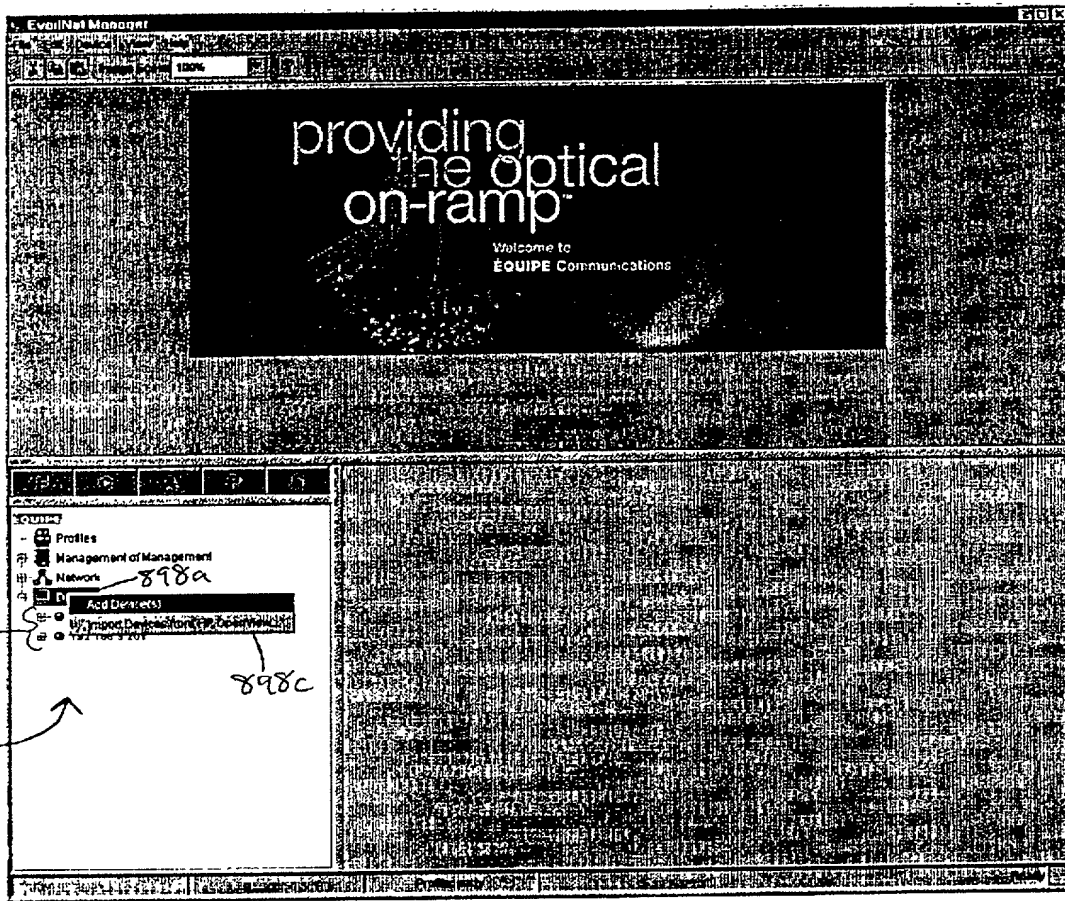
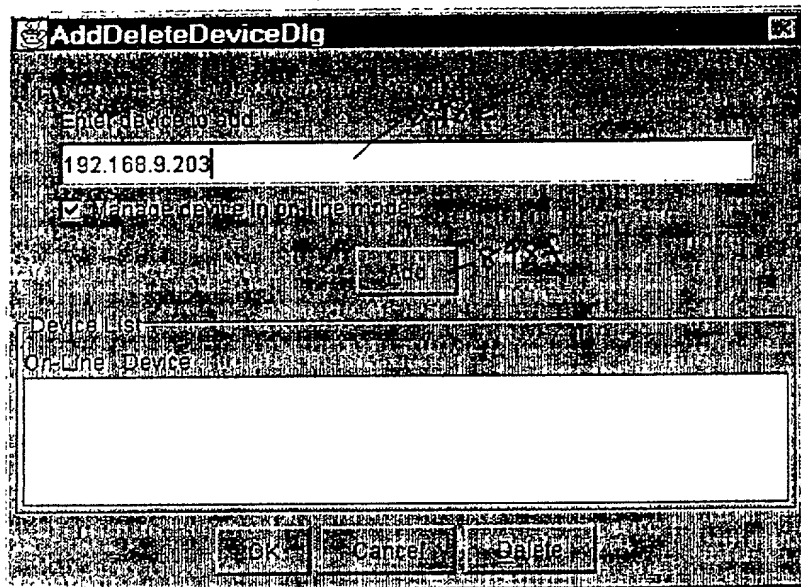


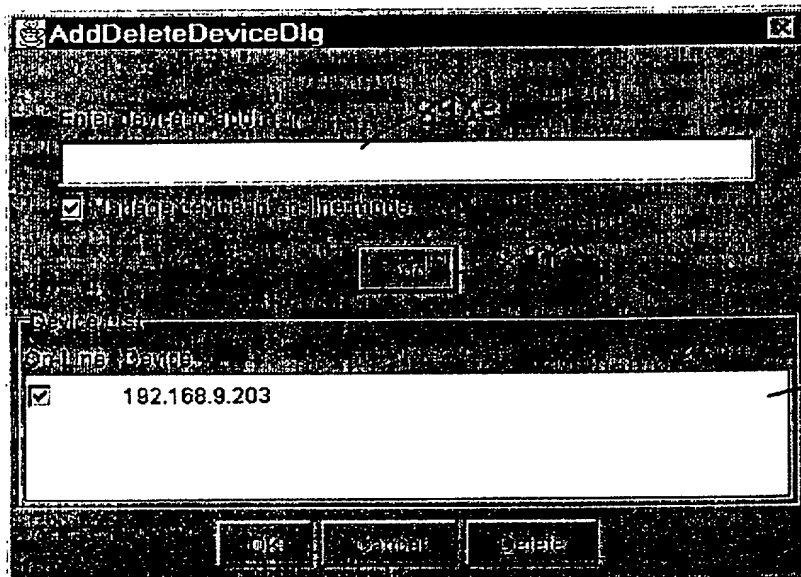
Fig. 4b

Fig. 4c



898d

Fig. 4d



898d

898g

898j

898i

898h

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895

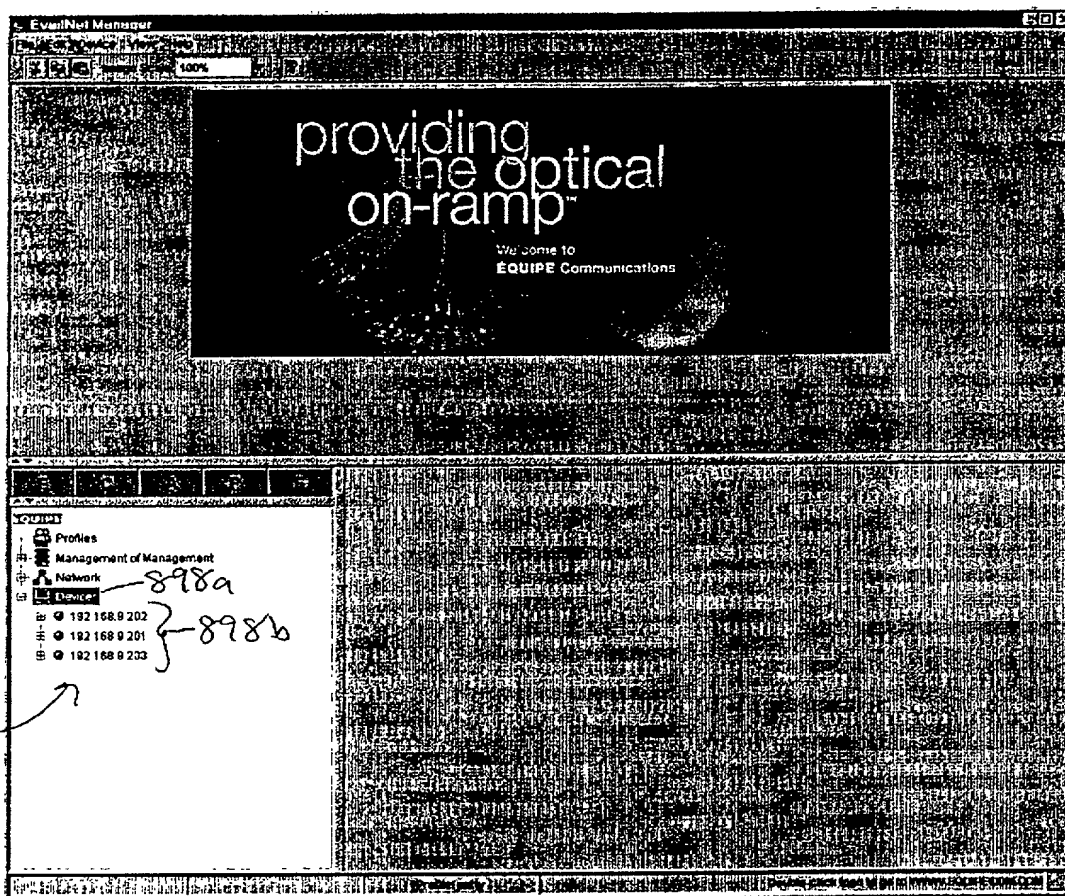


Fig. 4e



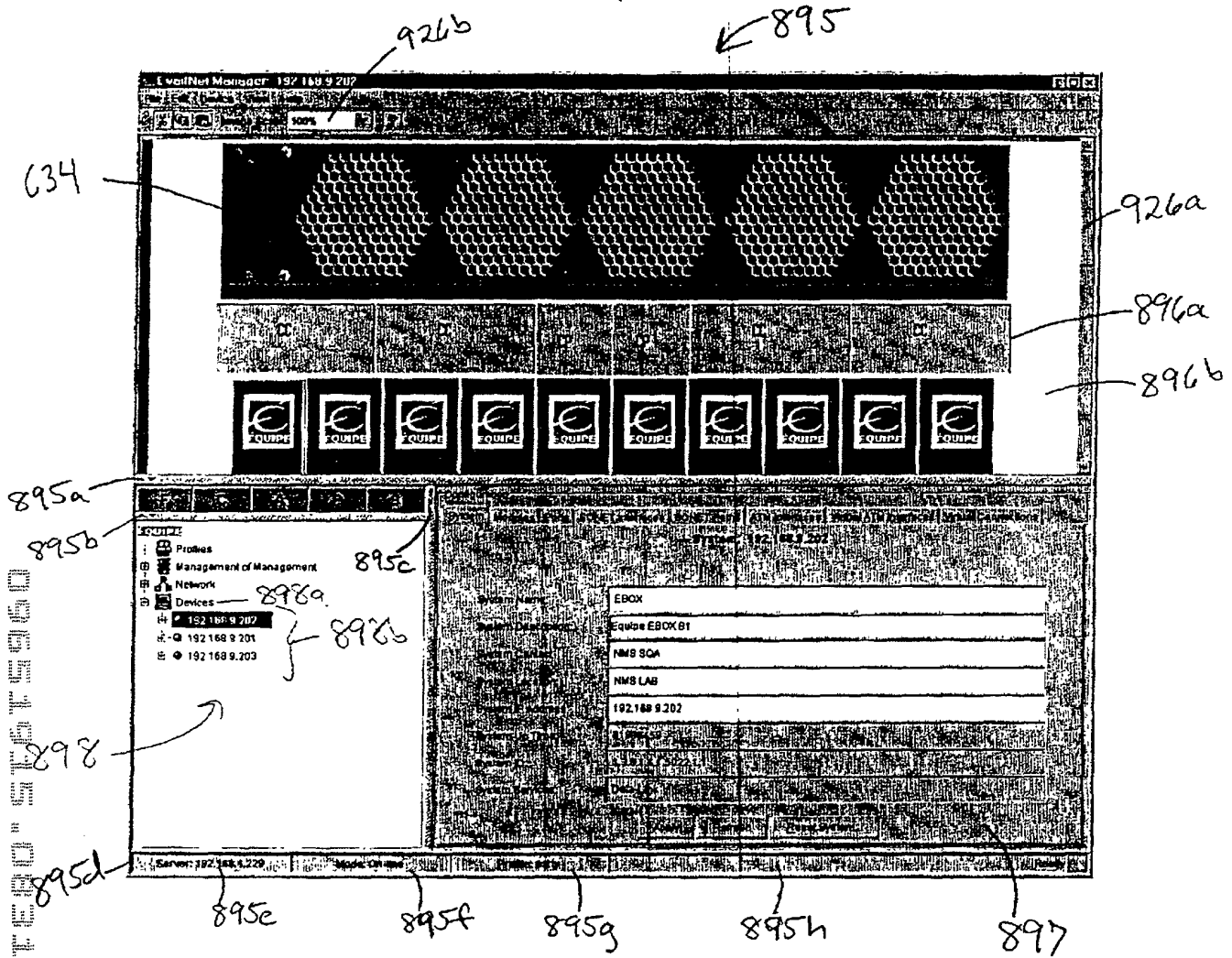


Fig. 4f

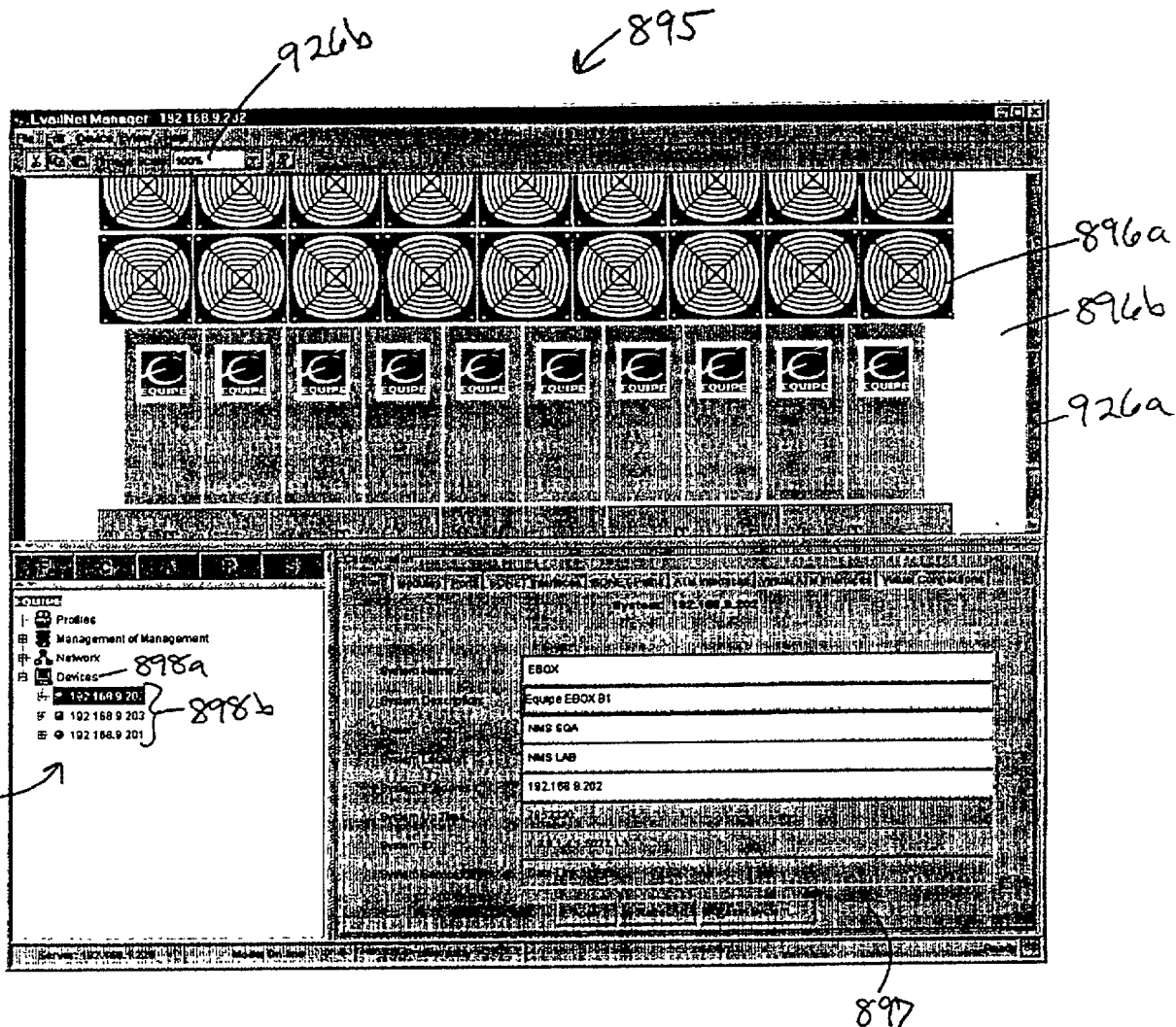
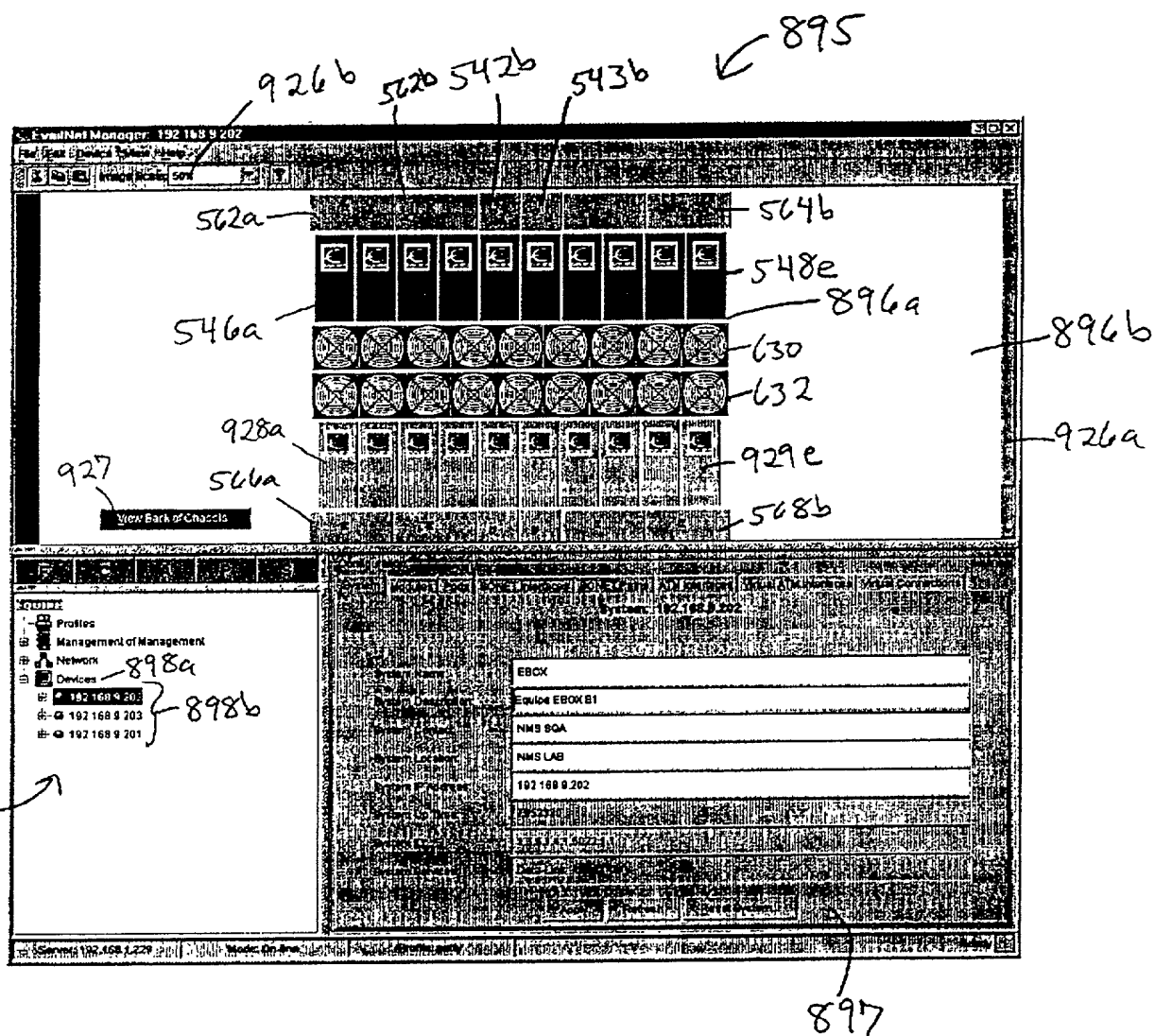


Fig. 4g



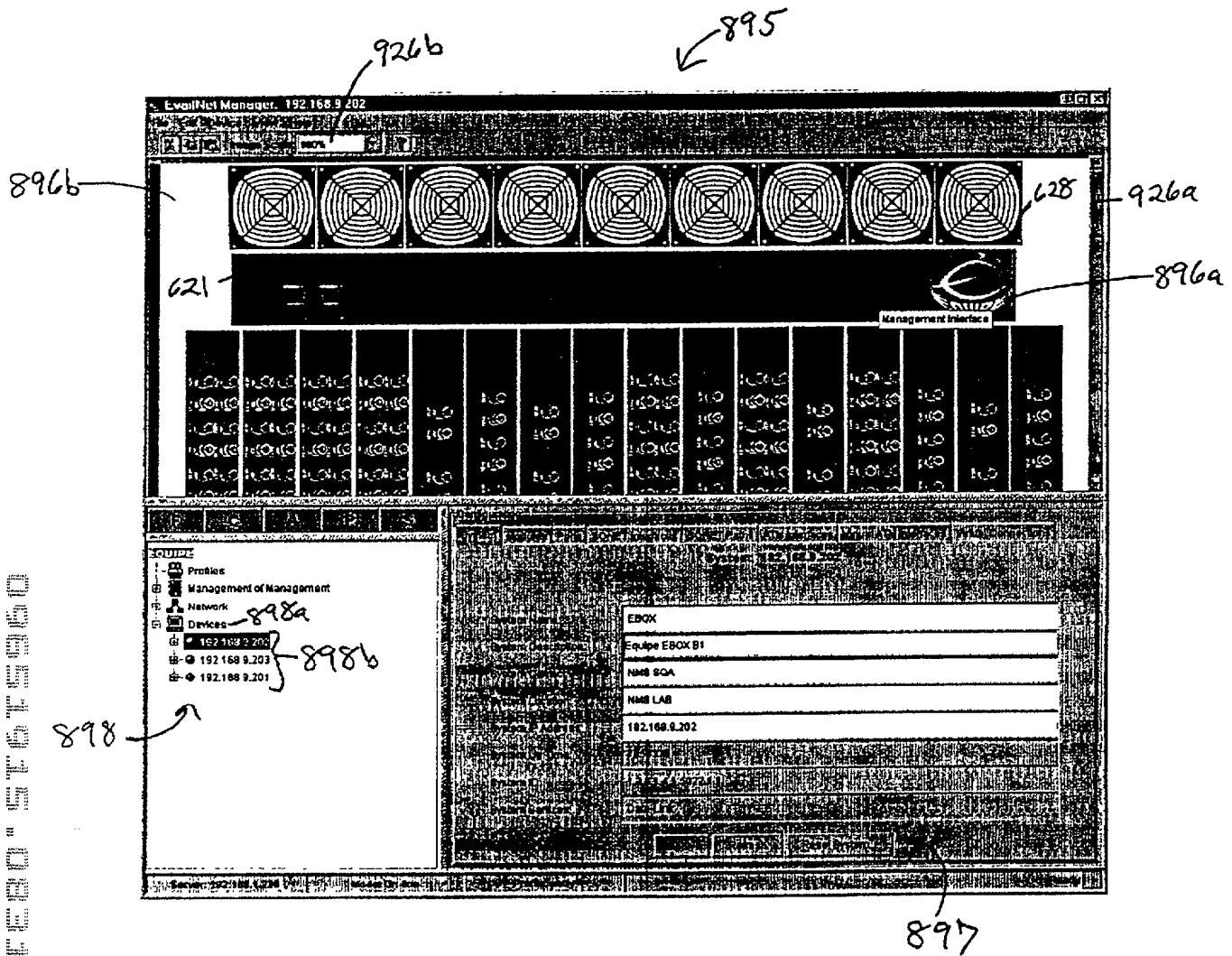


Fig. 4:

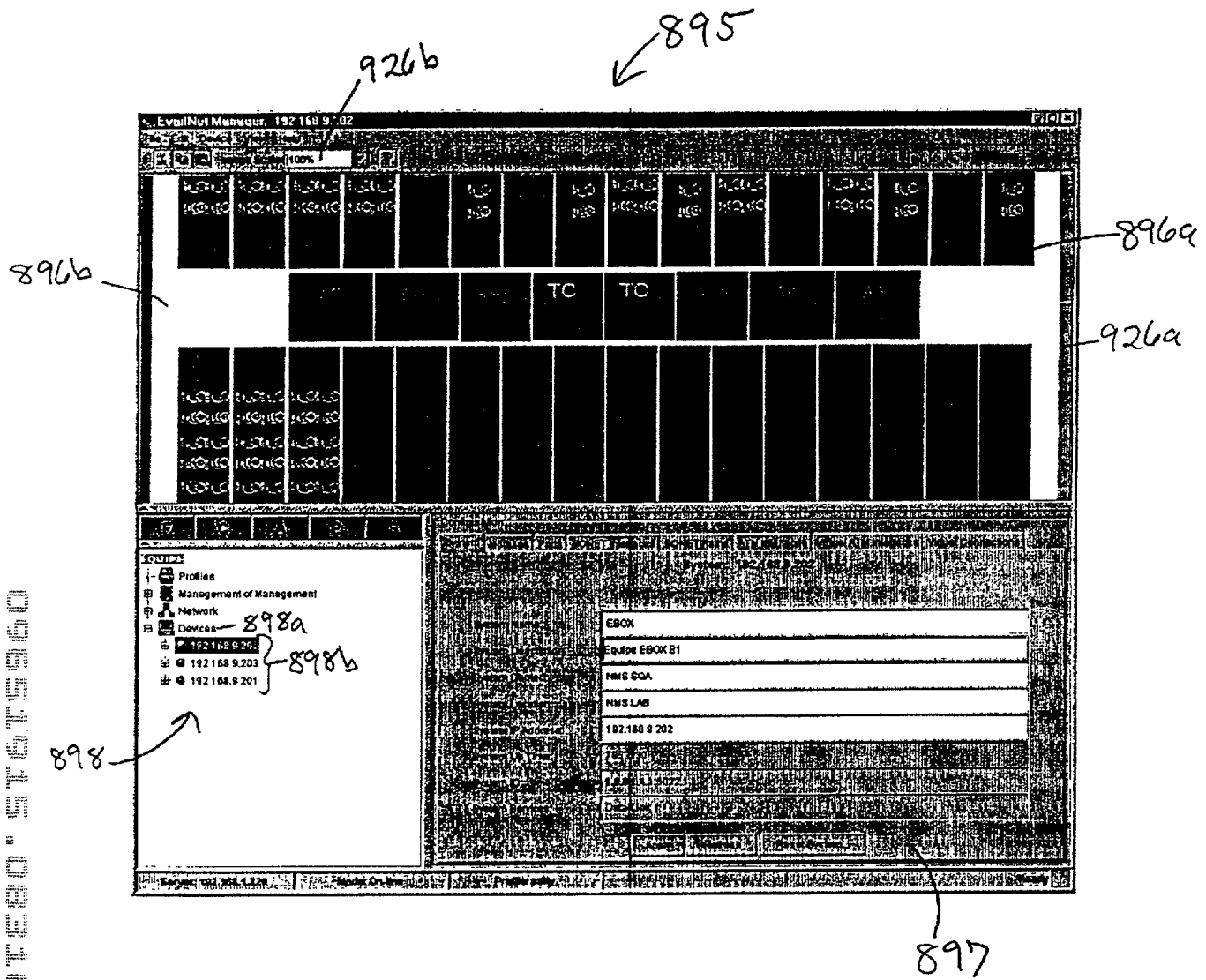


Fig. 4j

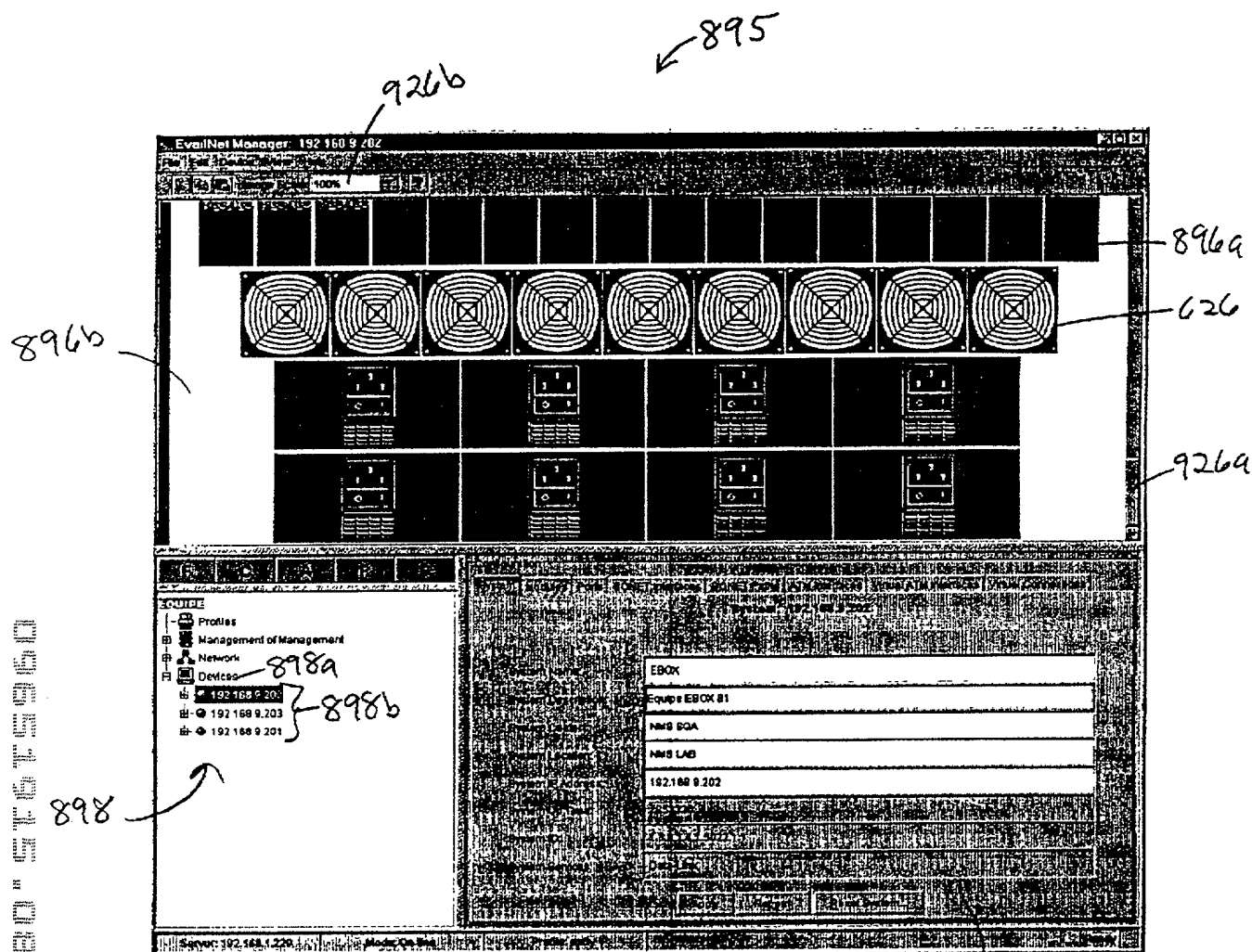
[illegible]

Fig. 4K

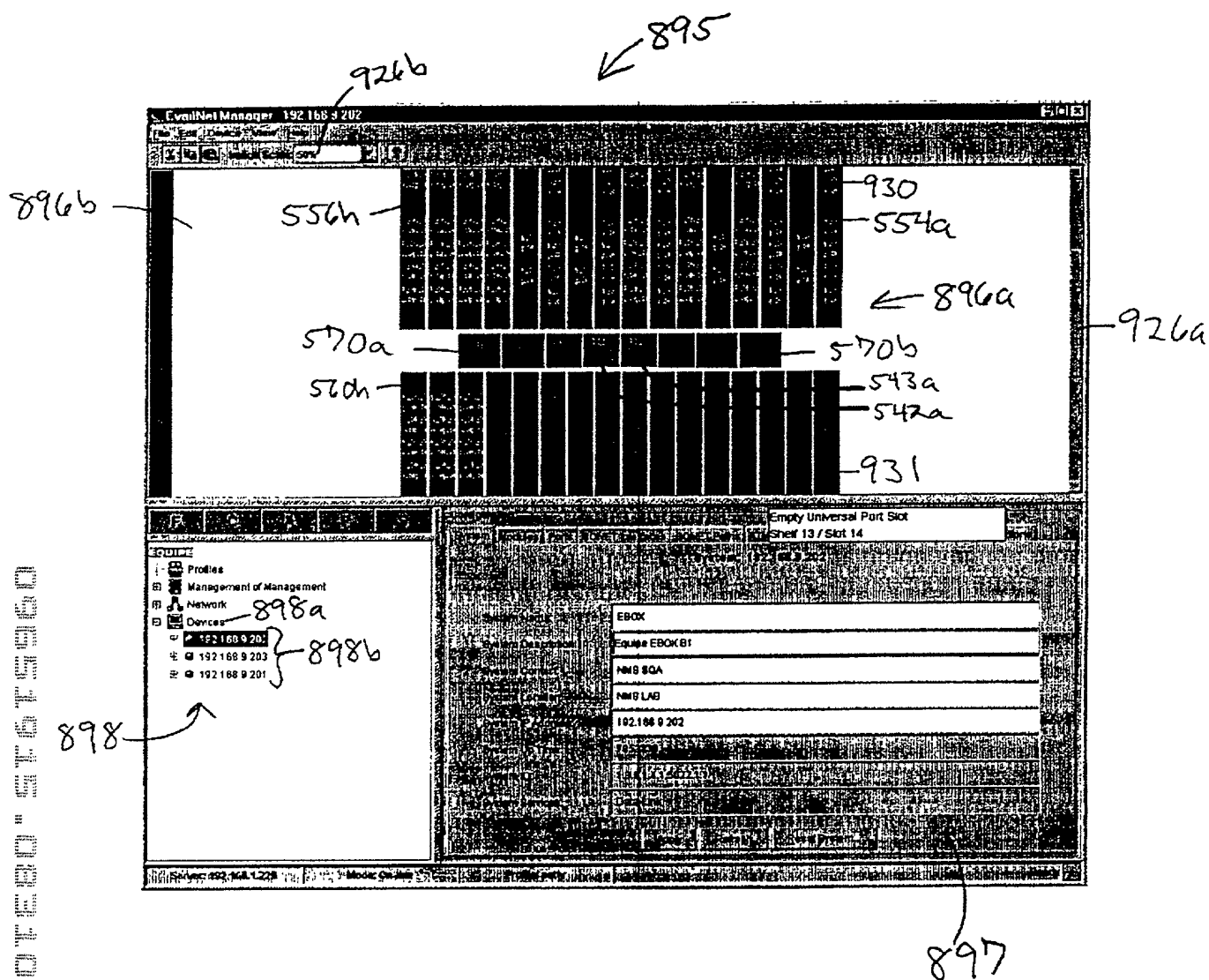


Fig. 4L

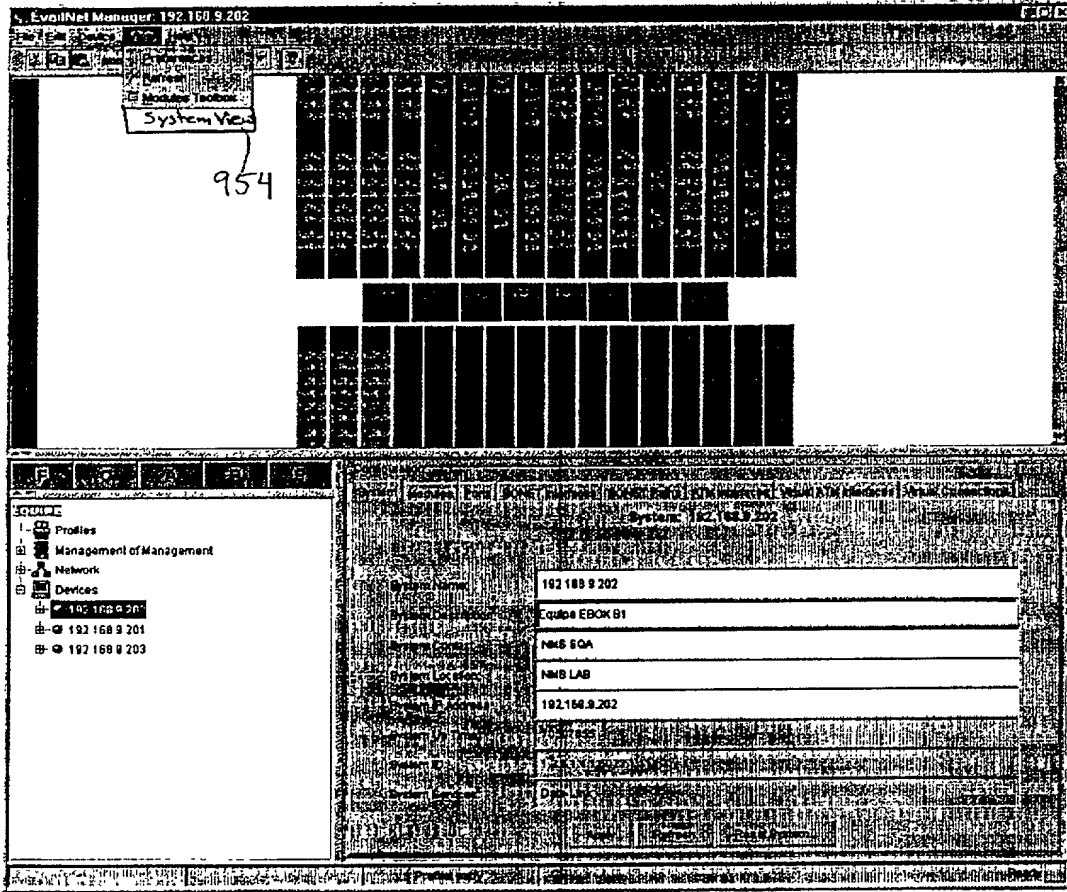


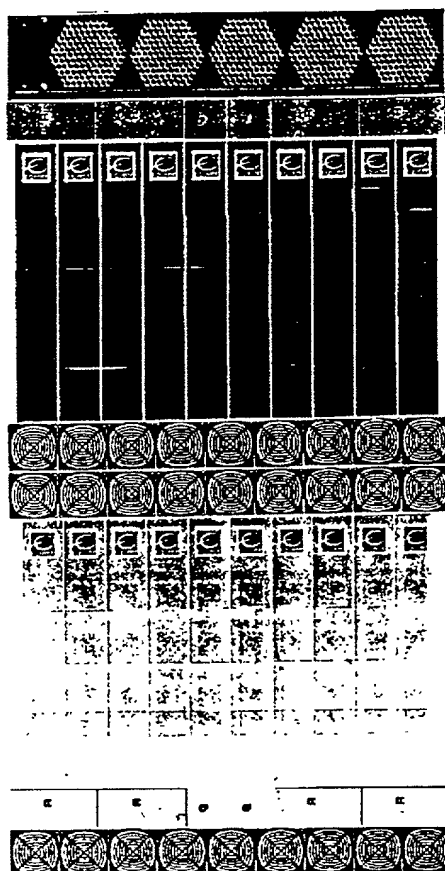
Fig. 4m

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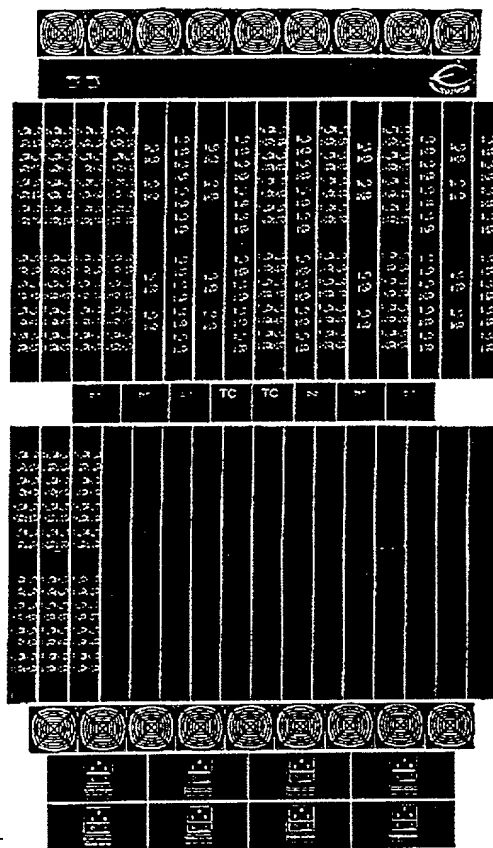


955

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955a



955b

Fig. 4n

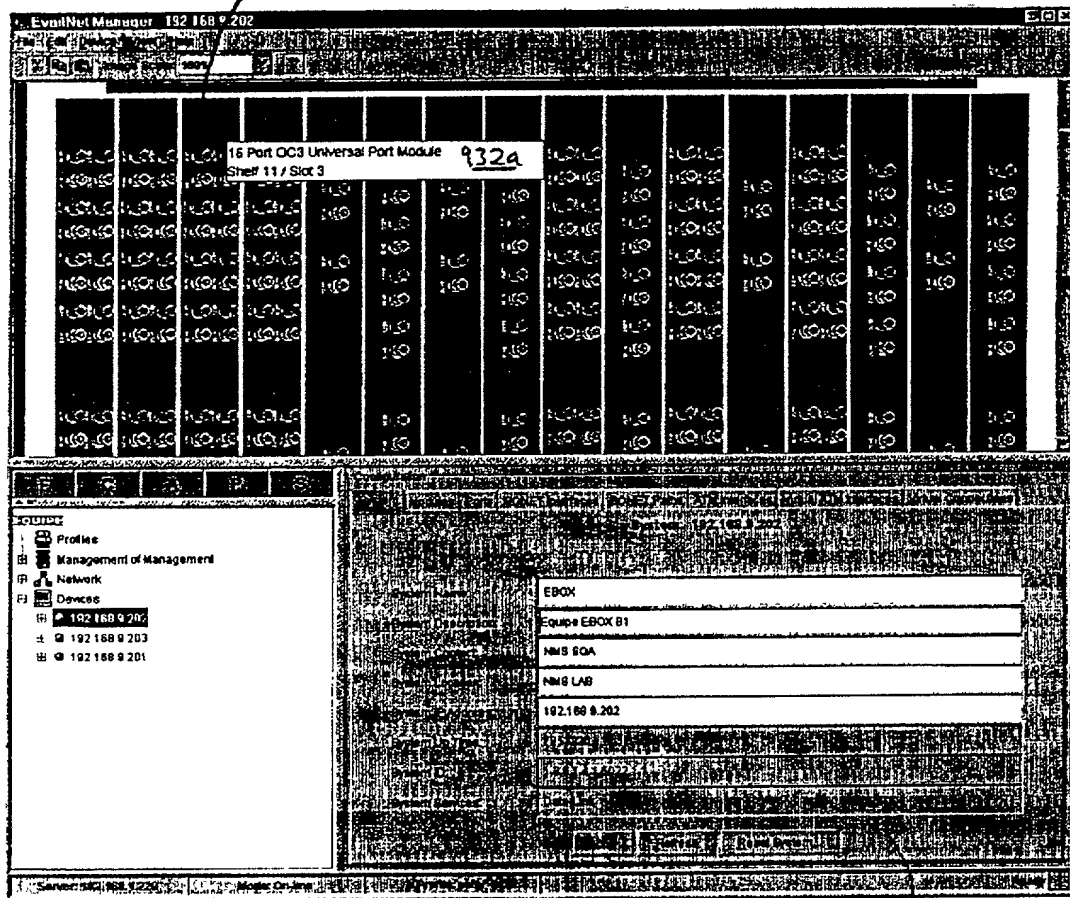


Fig.40

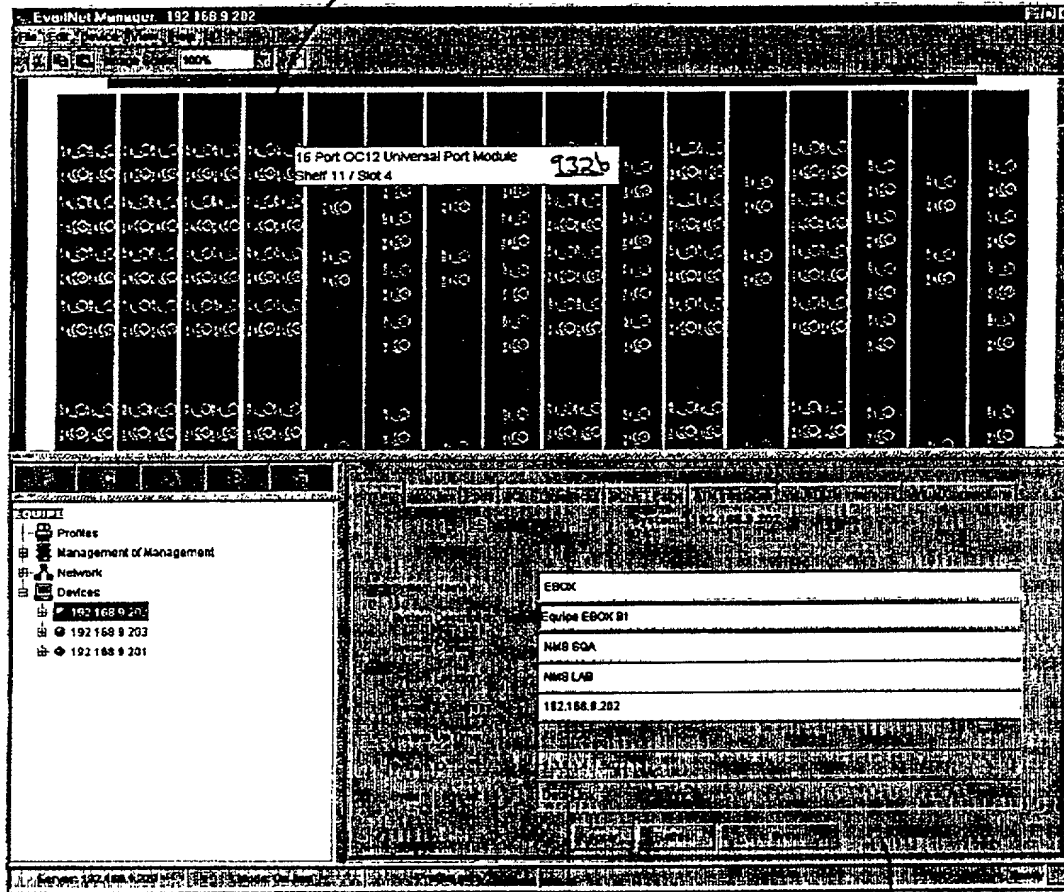


Fig. 4p



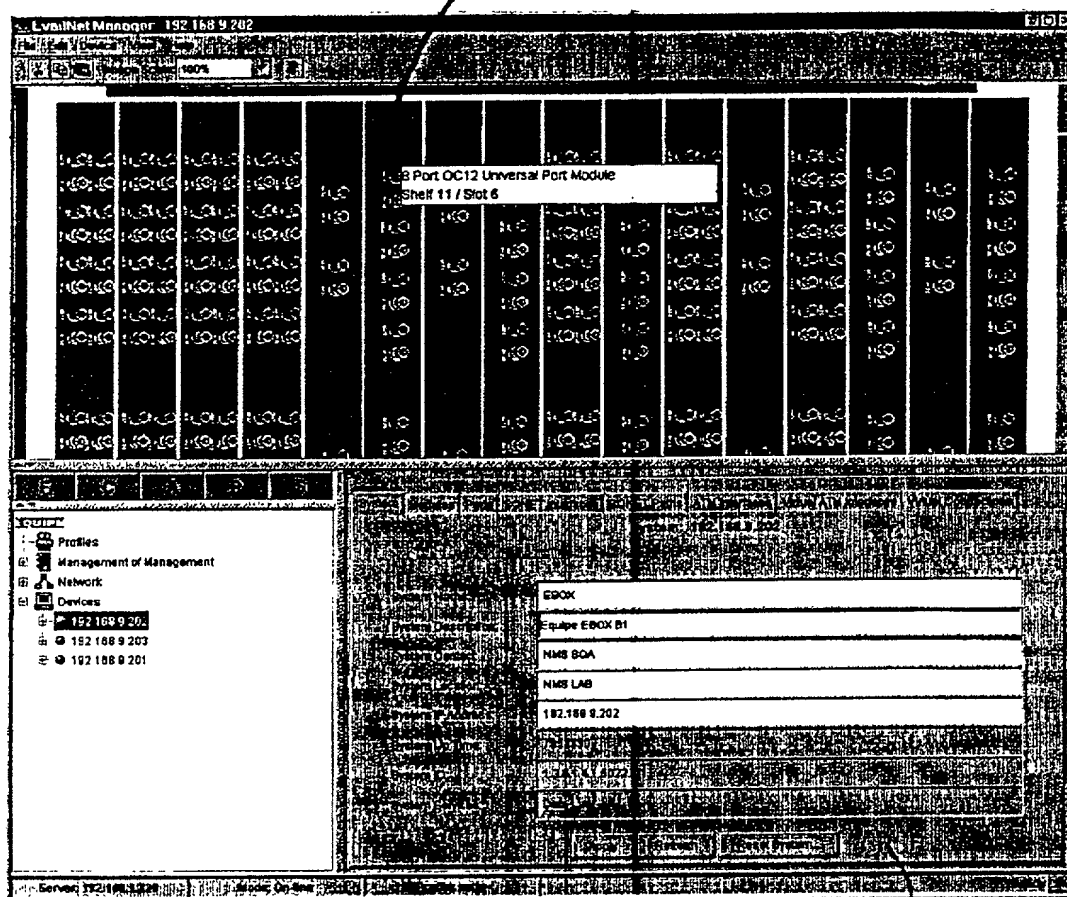
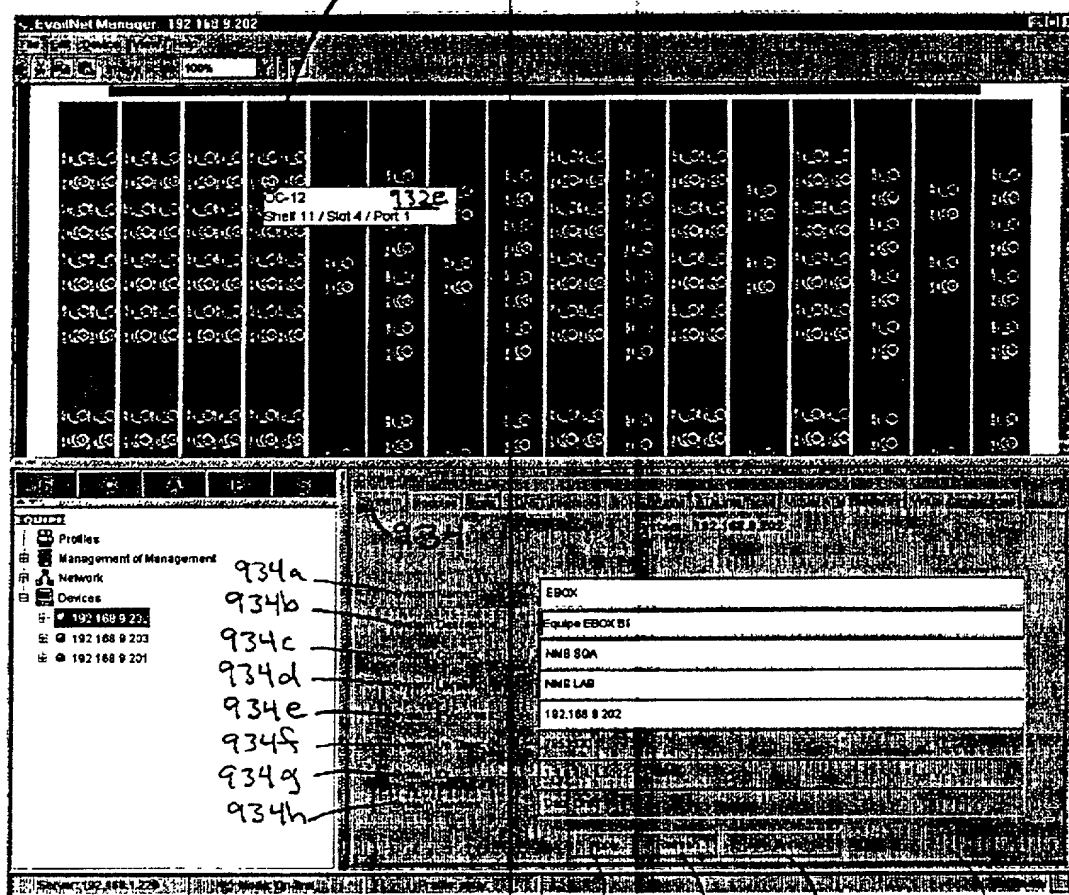
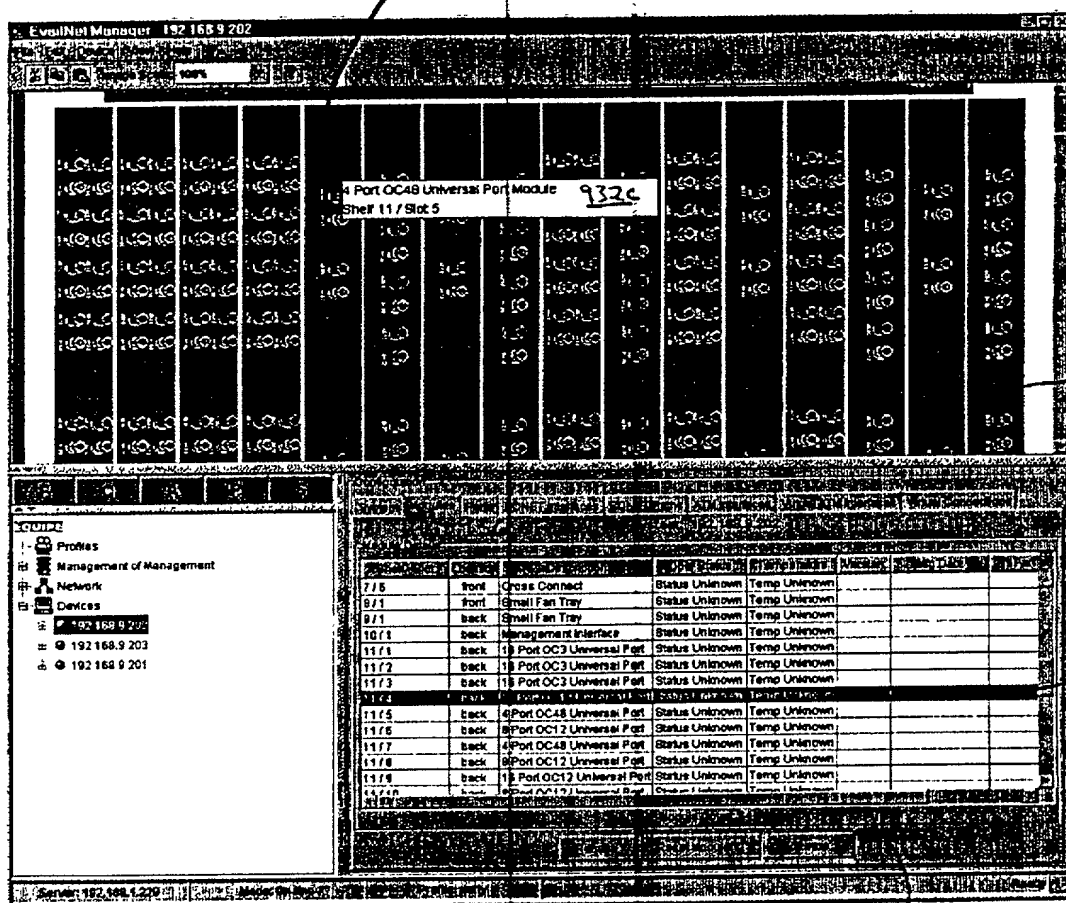
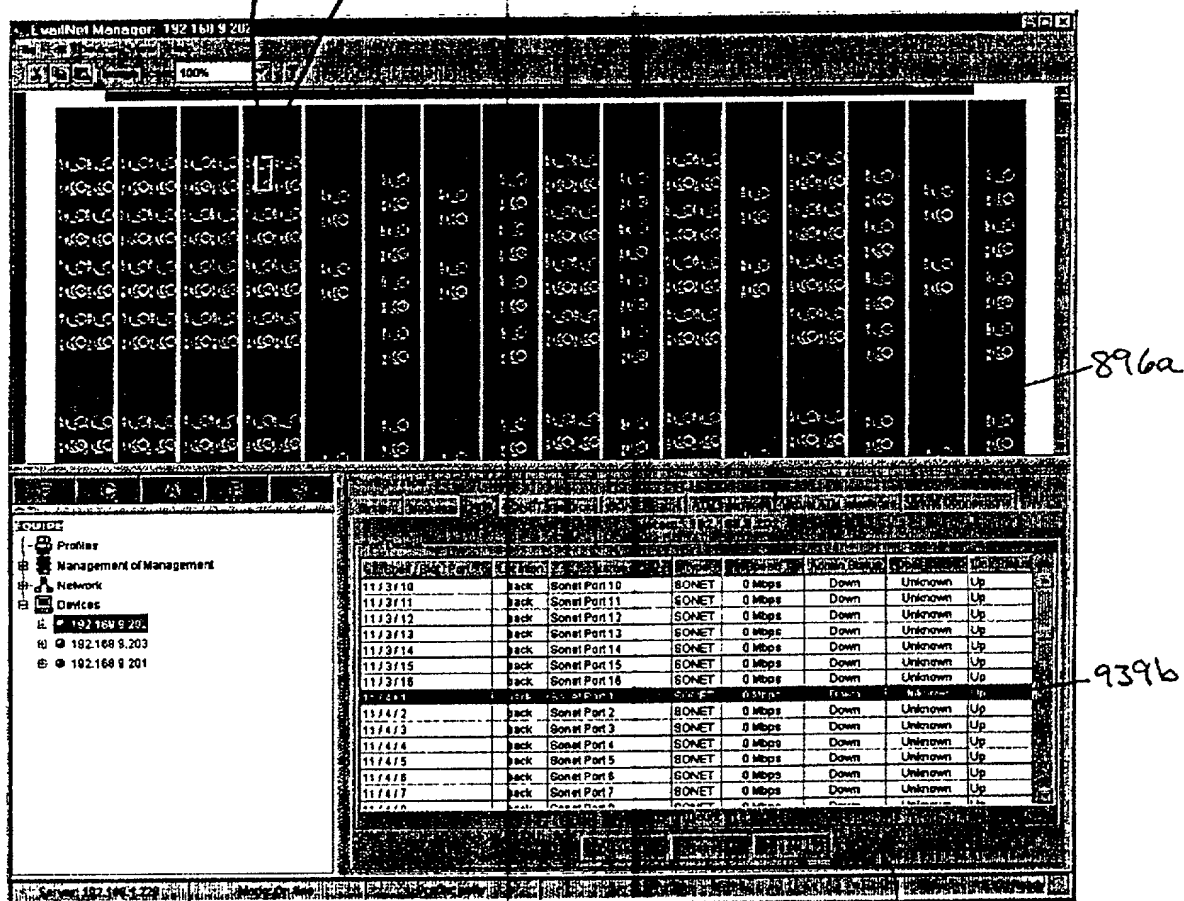
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Fig. 47

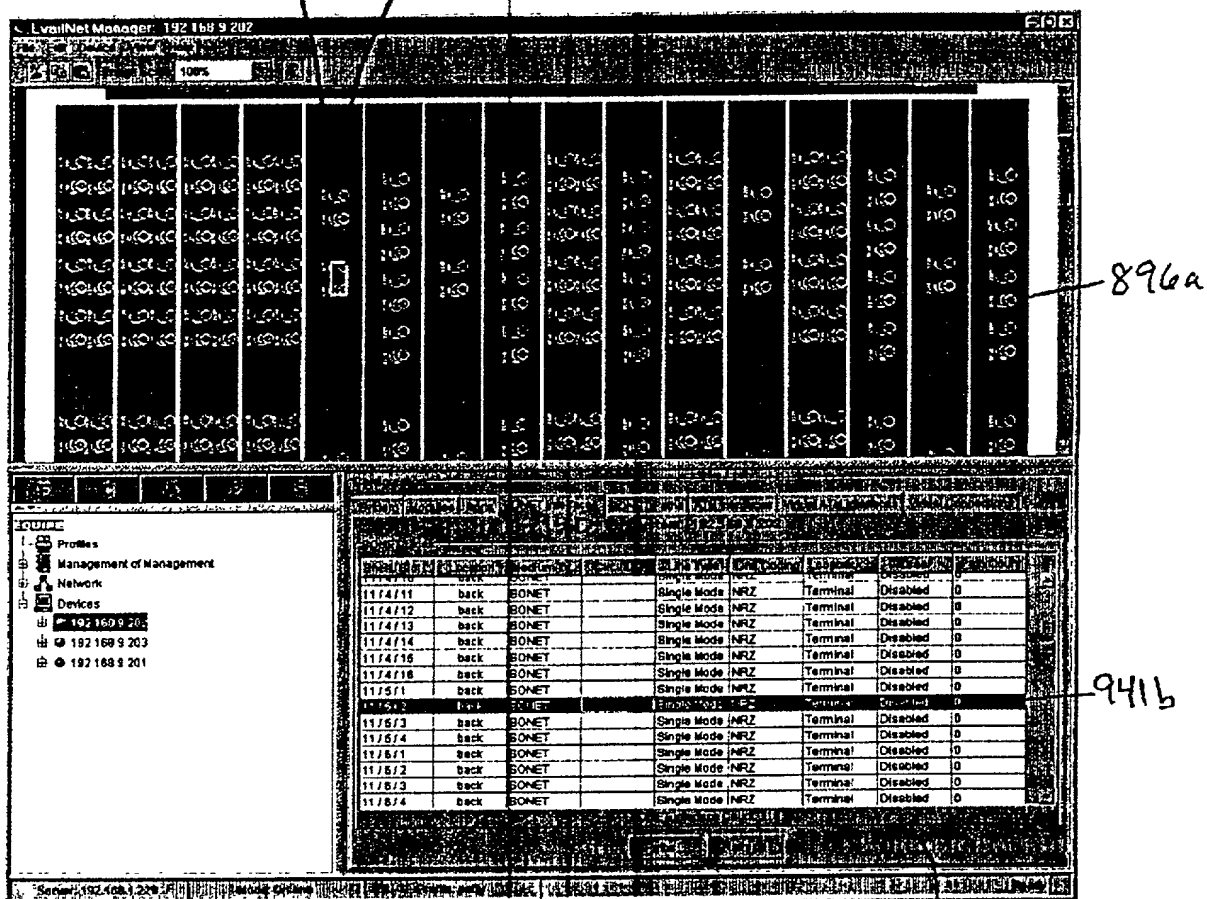








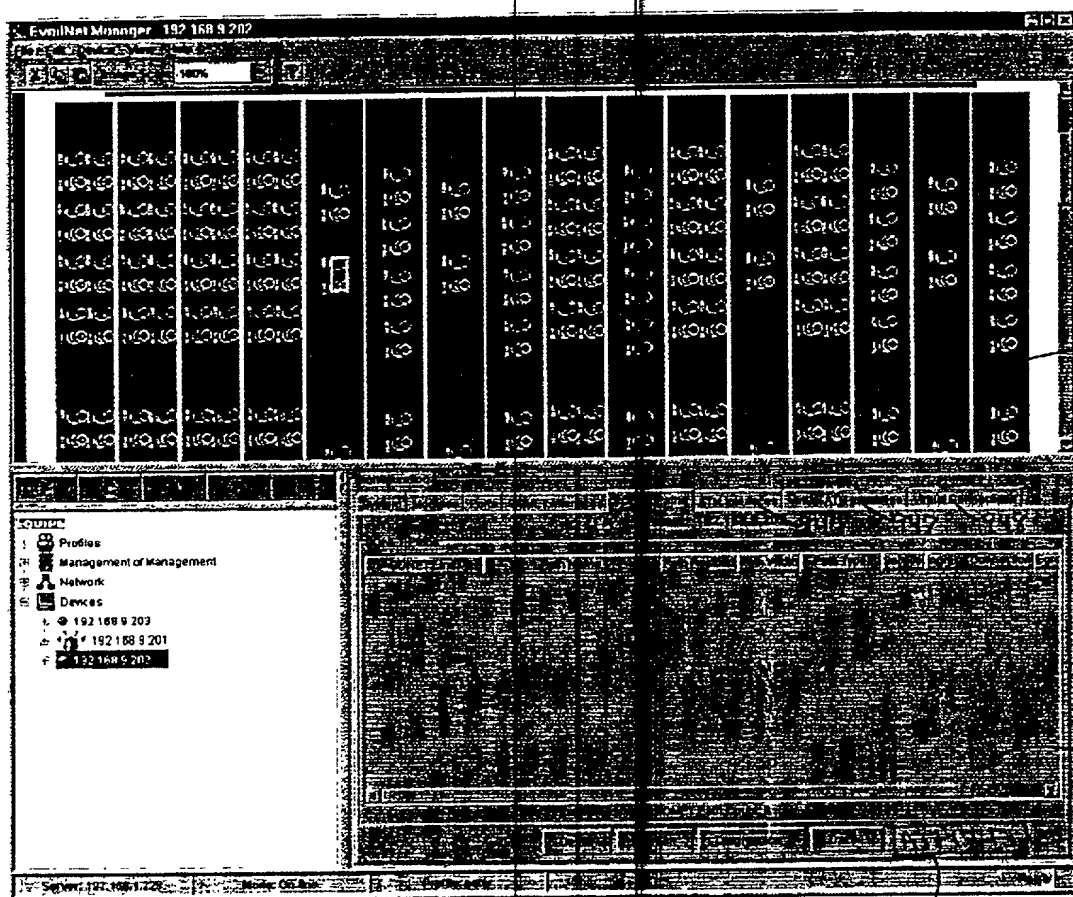
895



Parameter	Unit	Value	Standard Error	t-Statistic	p-Value
Intercept		0.000	0.000	0.000	1.000
Age	Years	0.000	0.000	0.000	1.000
Gender		0.000	0.000	0.000	1.000
Marital Status		0.000	0.000	0.000	1.000
Education	Years	0.000	0.000	0.000	1.000
Income	USD	0.000	0.000	0.000	1.000
Health		0.000	0.000	0.000	1.000
Religion		0.000	0.000	0.000	1.000
Occupation		0.000	0.000	0.000	1.000
Region		0.000	0.000	0.000	1.000
Time	Years	0.000	0.000	0.000	1.000
Constant		0.000	0.000	0.000	1.000

897

Fig. 4v



Parameter	Value	Unit
Initial temperature	25.0	°C
Final temperature	25.0	°C
Initial pressure	1.013	bar
Final pressure	1.013	bar
Initial volume	0.001	m³
Final volume	0.001	m³
Initial mass	0.001	kg
Final mass	0.001	kg
Initial density	1000	kg/m³
Final density	1000	kg/m³
Initial viscosity	0.001	Pa·s
Final viscosity	0.001	Pa·s
Initial thermal conductivity	0.6	W/m·K
Final thermal conductivity	0.6	W/m·K
Initial specific heat capacity	4182	J/kg·K
Final specific heat capacity	4182	J/kg·K
Initial enthalpy	4182	J/kg
Final enthalpy	4182	J/kg
Initial entropy	1.306	J/kg·K
Final entropy	1.306	J/kg·K
Initial internal energy	4182	J/kg
Final internal energy	4182	J/kg
Initial Gibbs free energy	-16.75	kJ/mol
Final Gibbs free energy	-16.75	kJ/mol
Initial Helmholtz free energy	-16.75	kJ/mol
Final Helmholtz free energy	-16.75	kJ/mol
Initial chemical potential	-16.75	kJ/mol
Final chemical potential	-16.75	kJ/mol
Initial activity	1.0	
Final activity	1.0	
Initial fugacity	1.013	bar
Final fugacity	1.013	bar
Initial vapor pressure	0.003	bar
Final vapor pressure	0.003	bar
Initial boiling point	100.0	°C
Final boiling point	100.0	°C
Initial melting point	0.0	°C
Final melting point	0.0	°C
Initial triple point	0.01	°C
Final triple point	0.01	°C
Initial critical point	373.95	°C
Final critical point	373.95	°C
Initial normal boiling point	100.0	°C
Final normal boiling point	100.0	°C
Initial normal melting point	0.0	°C
Final normal melting point	0.0	°C
Initial normal triple point	0.01	°C
Final normal triple point	0.01	°C
Initial normal critical point	373.95	°C
Final normal critical point	373.95	°C
Initial normal vapor pressure	0.003	bar
Final normal vapor pressure	0.003	bar
Initial normal boiling point	100.0	°C
Final normal boiling point	100.0	°C
Initial normal melting point	0.0	°C
Final normal melting point	0.0	°C
Initial normal triple point	0.01	°C
Final normal triple point	0.01	°C
Initial normal critical point	373.95	°C
Final normal critical point	373.95	°C
Initial normal vapor pressure	0.003	bar
Final normal vapor pressure	0.003	bar
Initial normal boiling point	100.0	°C
Final normal boiling point	100.0	°C
Initial normal melting point	0.0	°C
Final normal melting point	0.0	°C
Initial normal triple point	0.01	°C
Final normal triple point	0.01	°C
Initial normal critical point	373.95	°C
Final normal critical point	373.95	°C
Initial normal vapor pressure	0.003	bar
Final normal vapor pressure	0.003	bar
Initial normal boiling point	100.0	°C
Final normal boiling point	100.0	°C
Initial normal melting point	0.0	°C
Final normal melting point	0.0	°C
Initial normal triple point	0.01	°C
Final normal triple point	0.01	°C
Initial normal critical point	373.95	°C
Final normal critical point	373.95	°C
Initial normal vapor pressure	0.003	bar
Final normal vapor pressure	0.003	bar
Initial normal boiling point	100.0	°C
Final normal boiling point	100.0	°C
Initial normal melting point	0.0	°C
Final normal melting point	0.0	°C
Initial normal triple point	0.01	°C
Final normal triple point	0.01	°C
Initial normal critical point	373.95	°C
Final normal critical point	373.95	°C
Initial normal vapor pressure	0.003	bar
Final normal vapor pressure	0.003	bar
Initial normal boiling point	100.0	°C
Final normal boiling point	100.0	°C
Initial normal melting point	0.0	°C
Final normal melting point	0.0	°C
Initial normal triple point	0.01	°C
Final normal triple point	0.01	°C
Initial normal critical point	373.95	°C
Final normal critical point	373.95	°C
Initial normal vapor pressure	0.003	bar
Final normal vapor pressure	0.003	bar
Initial normal boiling point	100.0	°C
Final normal boiling point	100.0	°C
Initial normal melting point	0.0	°C
Final normal melting point	0.0	°C
Initial normal triple point	0.01	°C
Final normal triple point	0.01	°C
Initial normal critical point	373.95	°C
Final normal critical point	373.95	°C
Initial normal vapor pressure	0.003	bar
Final normal vapor pressure	0.003	bar
Initial normal boiling point	100.0	°C
Final normal boiling point	100.0	°C
Initial normal melting point	0.0	°C
Final normal melting point	0.0	°C

Fig. 4w

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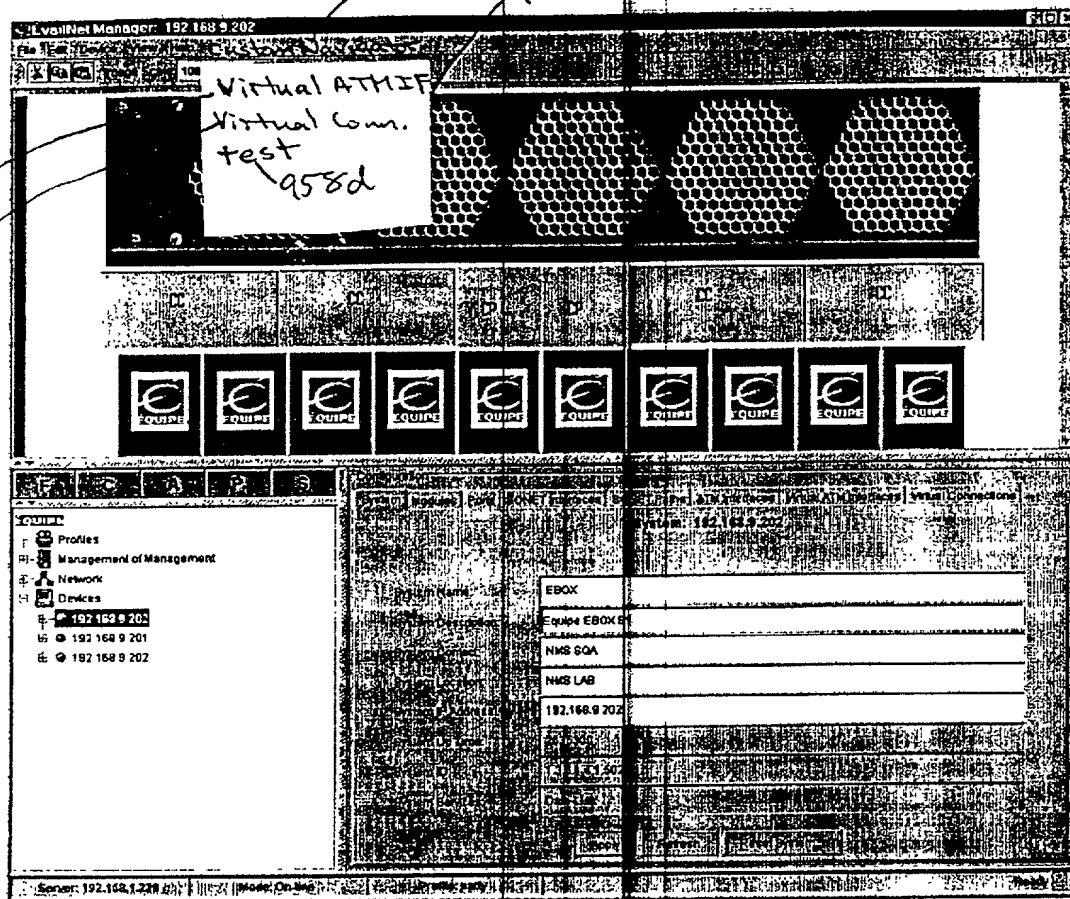


Fig. 4x

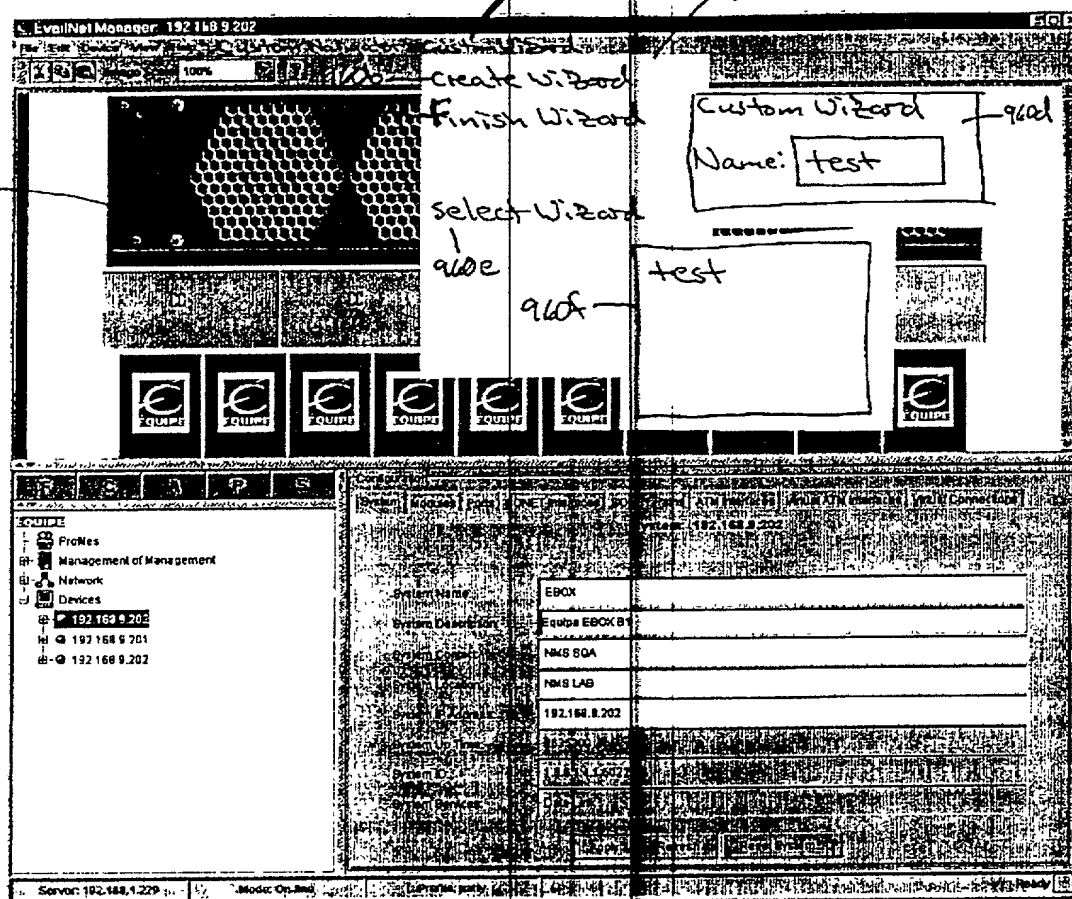


Fig. 4y

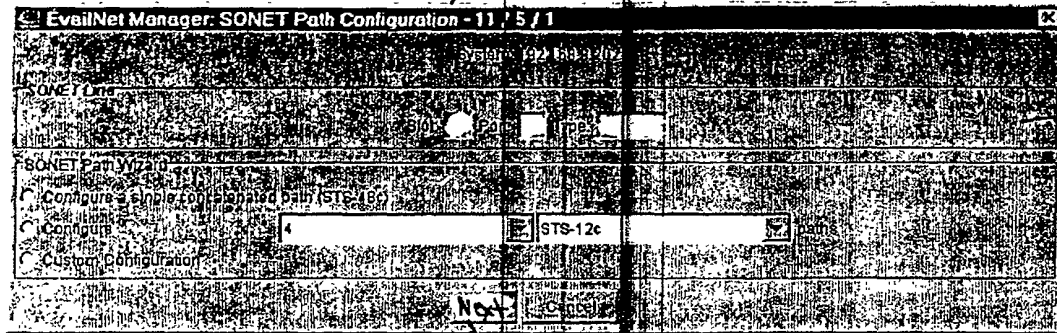


Fig. 42

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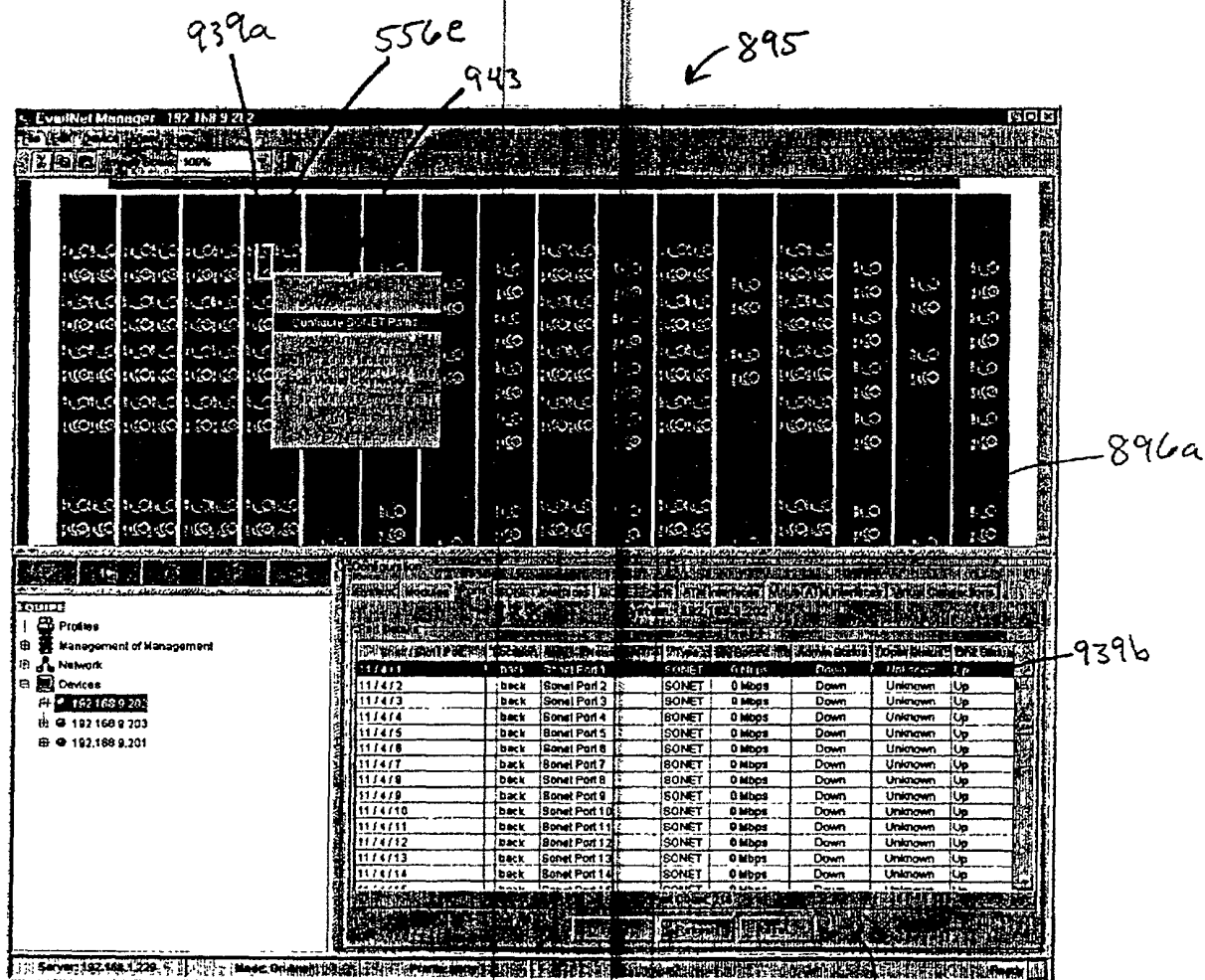




Fig. 5d

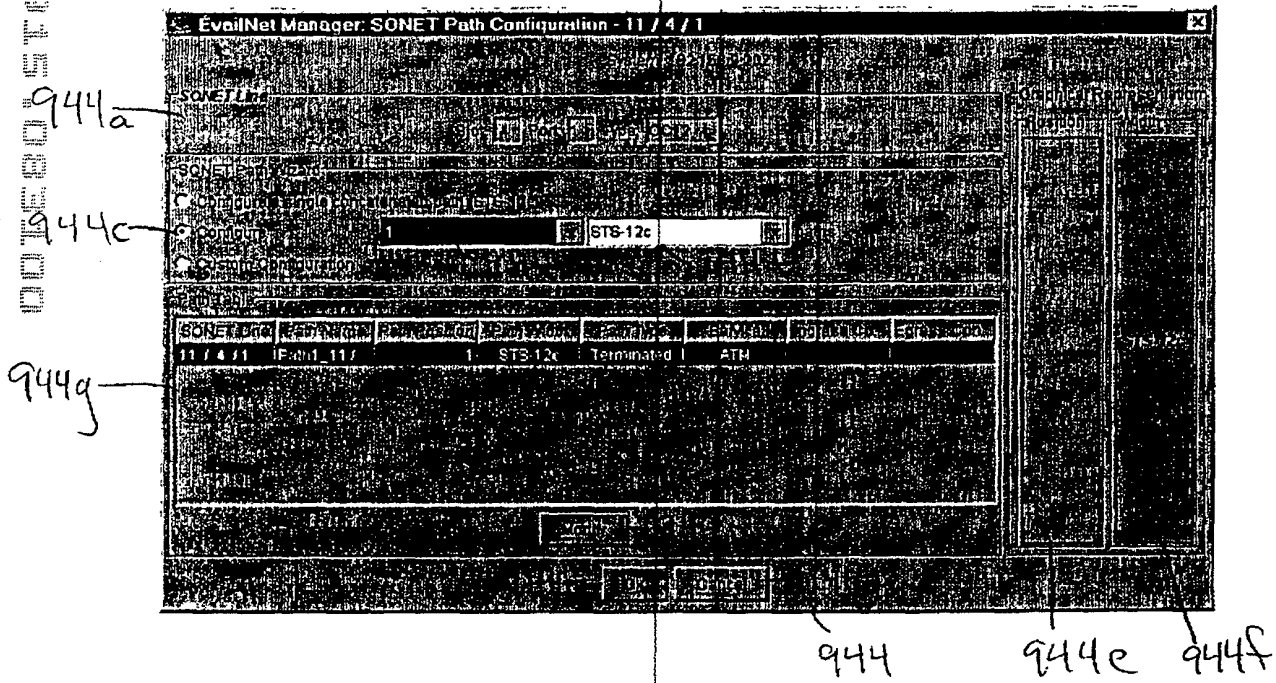
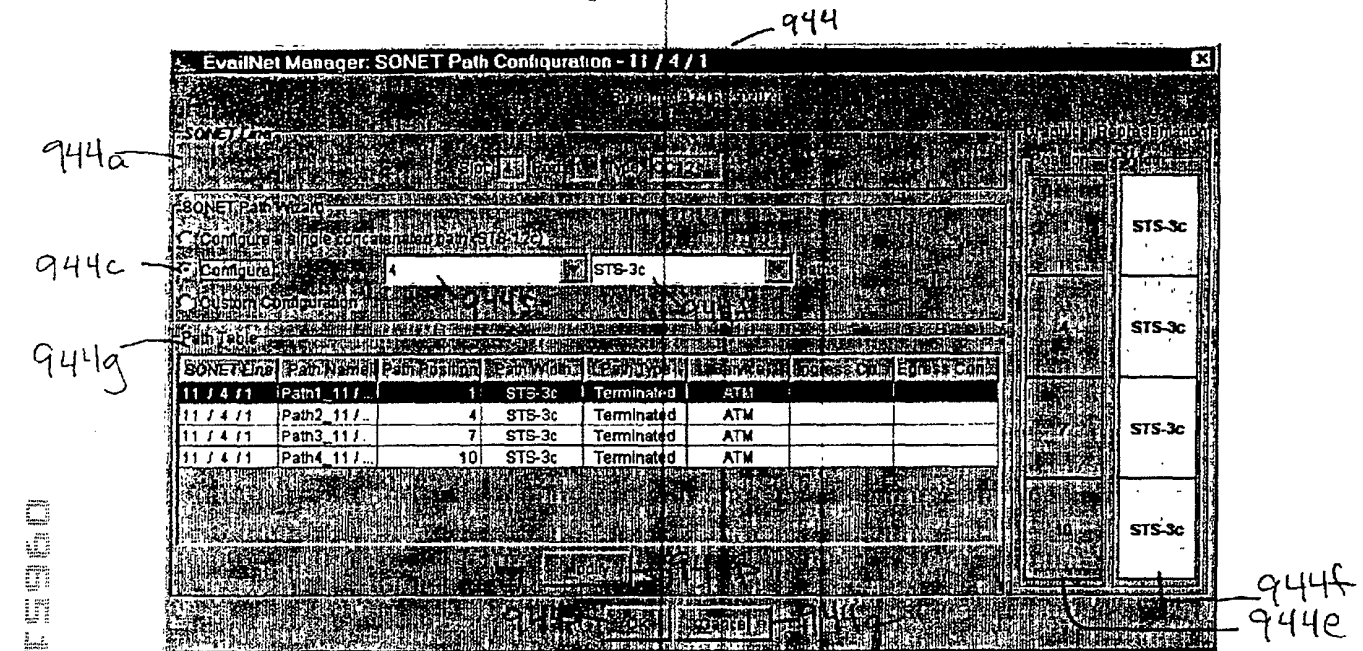


Fig. 5e



Fig. 5f

944

[illegible]

-944f  
-944e

EvalNet Manager: SONET Path Configuration - 11 / 4 / 1

SONE Line	Path Name	Path Cost	Path Type	Path Length	Path Delay	Path Delay	Path Delay	Path Delay	Path Delay	Path Delay
Shelf 11/S1...	Path1 11 / ...	1	3	2	1					
Shelf 11/S1...	Path2 11 / ...	4	3	2	1					

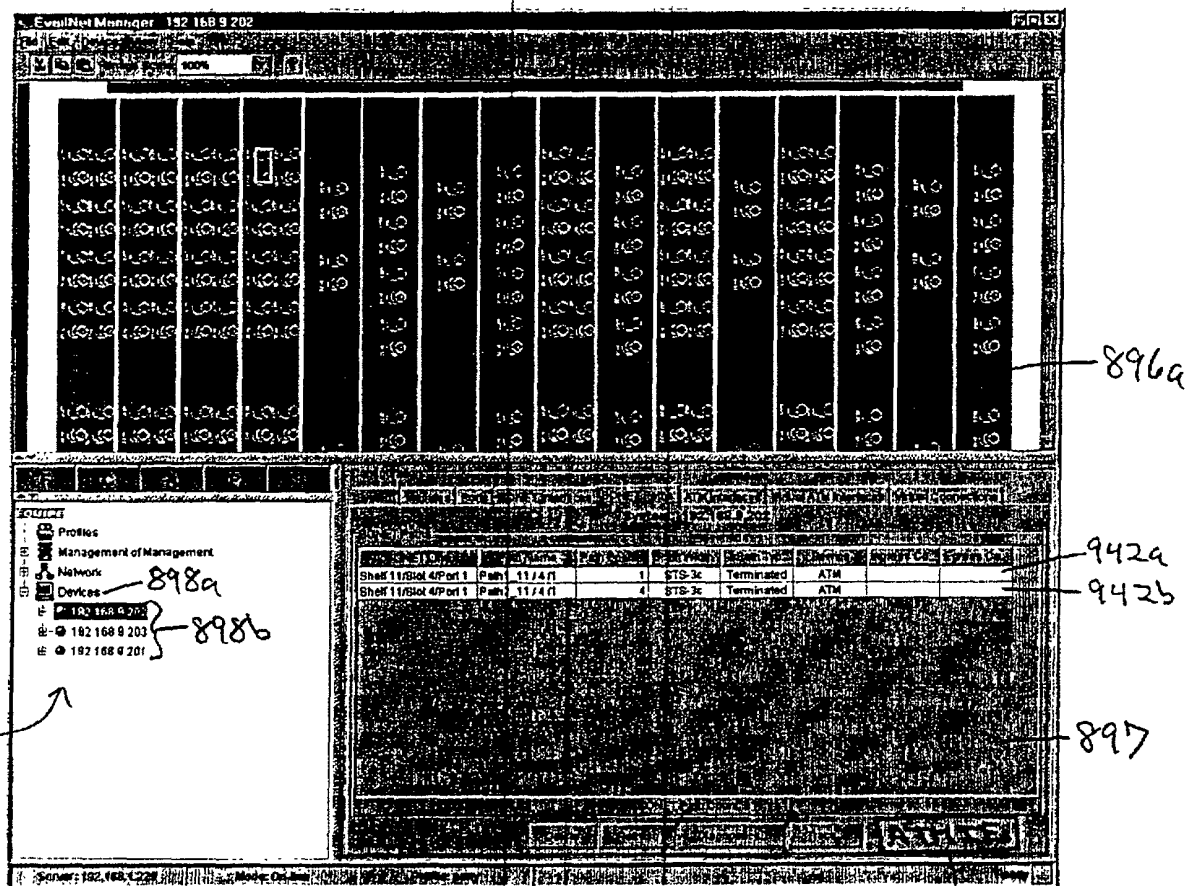
STS-3c

STS-3c

OK Cancel Help Print

945e      945f

Fig. 5g

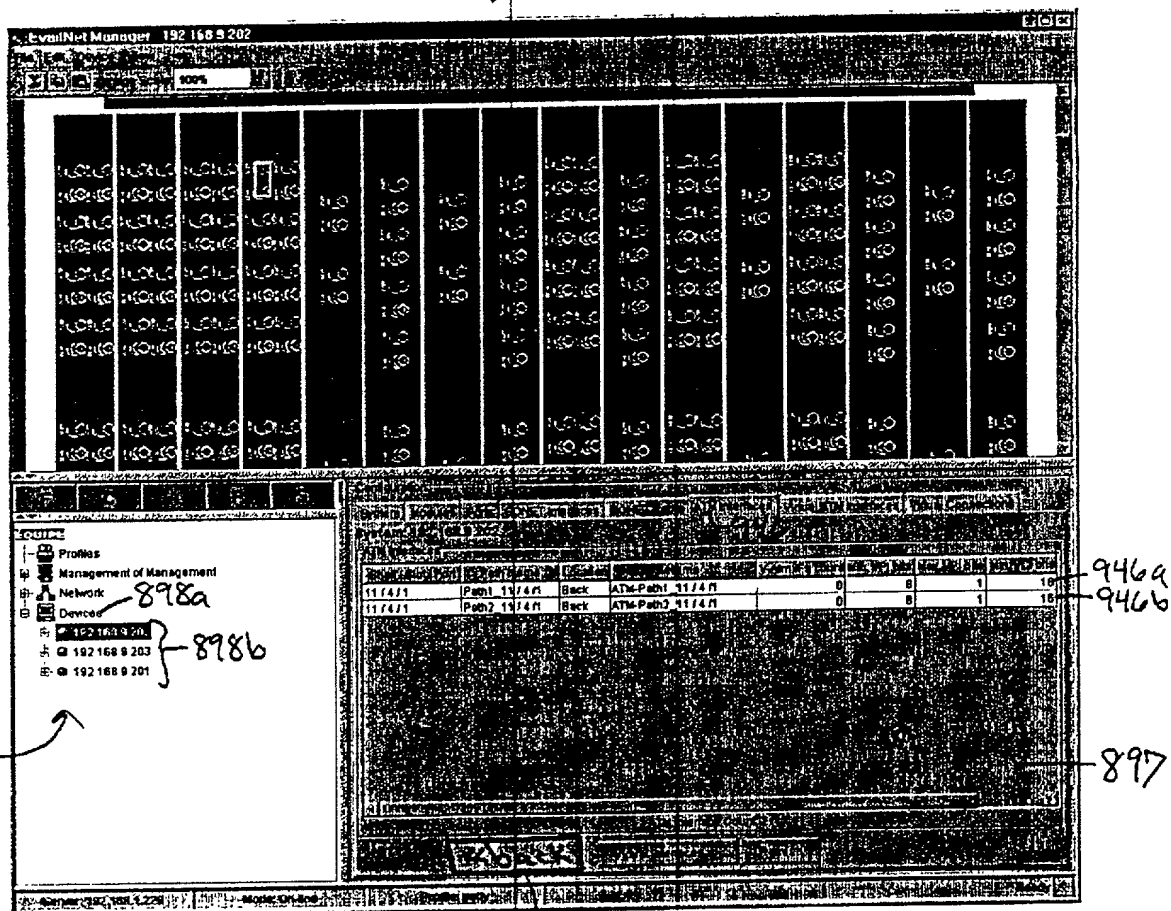


Descriptive statistics		Descriptive statistics		Descriptive statistics		Descriptive statistics		Descriptive statistics		
Variable	Mean	SD	Variable	Mean	SD	Variable	Mean	SD	Variable	Mean
Age	35.5	10.5	Age	35.5	10.5	Age	35.5	10.5	Age	35.5
Gender	0.5	0.5	Gender	0.5	0.5	Gender	0.5	0.5	Gender	0.5
Marital status	0.5	0.5	Marital status	0.5	0.5	Marital status	0.5	0.5	Marital status	0.5
Education	12.5	2.5	Education	12.5	2.5	Education	12.5	2.5	Education	12.5
Income	15.5	5.5	Income	15.5	5.5	Income	15.5	5.5	Income	15.5
Health status	1.5	1.5	Health status	1.5	1.5	Health status	1.5	1.5	Health status	1.5
Stress level	2.5	1.5	Stress level	2.5	1.5	Stress level	2.5	1.5	Stress level	2.5
Life satisfaction	3.5	1.5	Life satisfaction	3.5	1.5	Life satisfaction	3.5	1.5	Life satisfaction	3.5
Work satisfaction	4.5	1.5	Work satisfaction	4.5	1.5	Work satisfaction	4.5	1.5	Work satisfaction	4.5
Family satisfaction	5.5	1.5	Family satisfaction	5.5	1.5	Family satisfaction	5.5	1.5	Family satisfaction	5.5
Community satisfaction	6.5	1.5	Community satisfaction	6.5	1.5	Community satisfaction	6.5	1.5	Community satisfaction	6.5
Overall satisfaction	7.5	1.5	Overall satisfaction	7.5	1.5	Overall satisfaction	7.5	1.5	Overall satisfaction	7.5

Fig. 5h

942c

✓ 895



9466

Fig. 5:

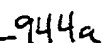
↙ 895



898.

940a

Fig. 5K



944

Fig. 5L

944

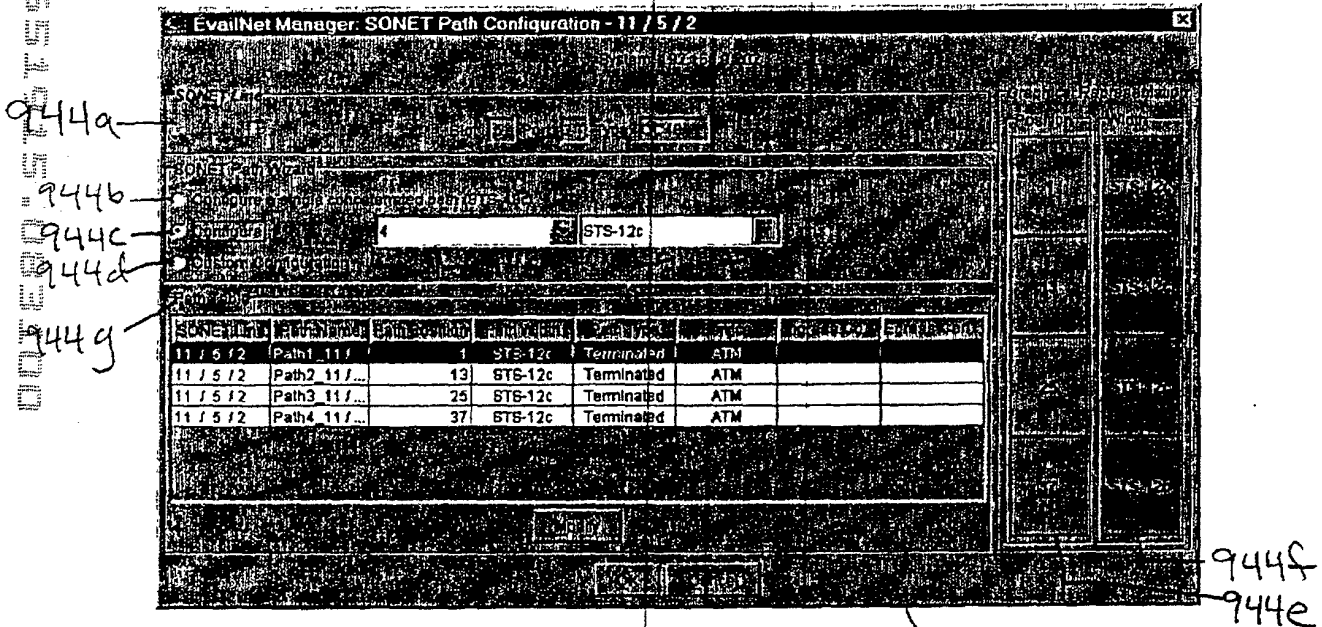
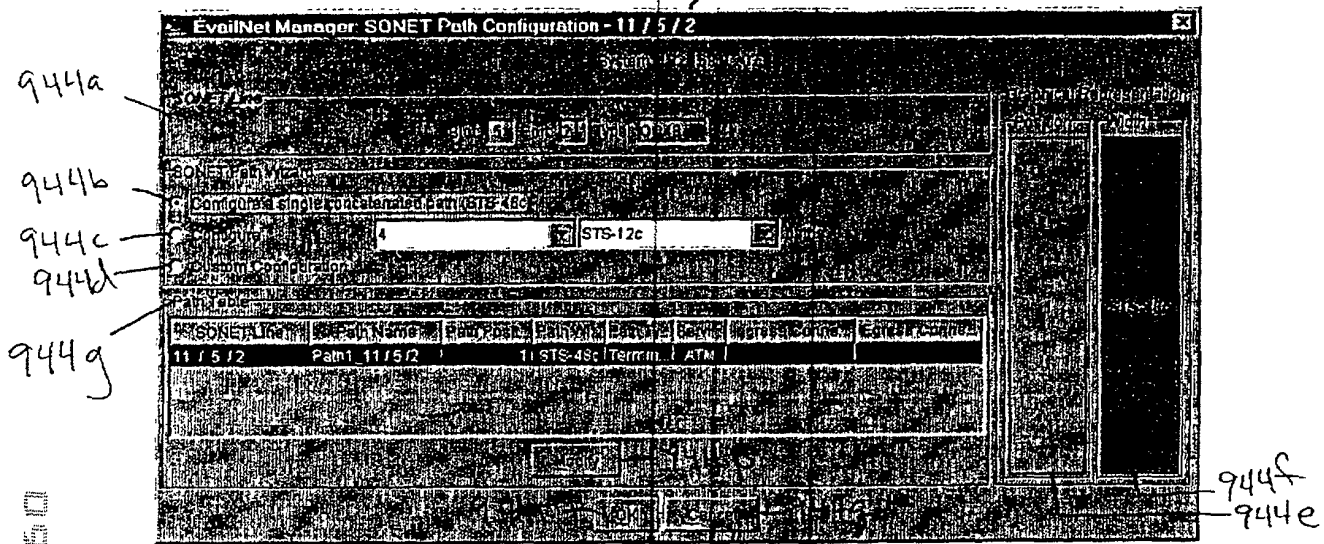


Fig. 5m

944

Fig. 5n

944

944a

944b

944c

944d

944g

EvailNet Manager: SONET Path Configuration - 11 / 5 / 2

SONET Path Configuration

Path Name: Path1 11 / 5 / 2

Path ID: 1

Path Type: STS-48c

Path Status: Terminated

Path Description: ATM

944f

944e

944a

944b

944c

944d

944g

EvailNet Manager: SONET Path Configuration - 11 / 5 / 2

SONET Path Configuration

Path Name: Path1 11 / 5 / 2

Path ID: 1

Path Type: STS-3c

Path Status: Terminated

Path Description: ATM

944f

944e

944

Fig. 5o

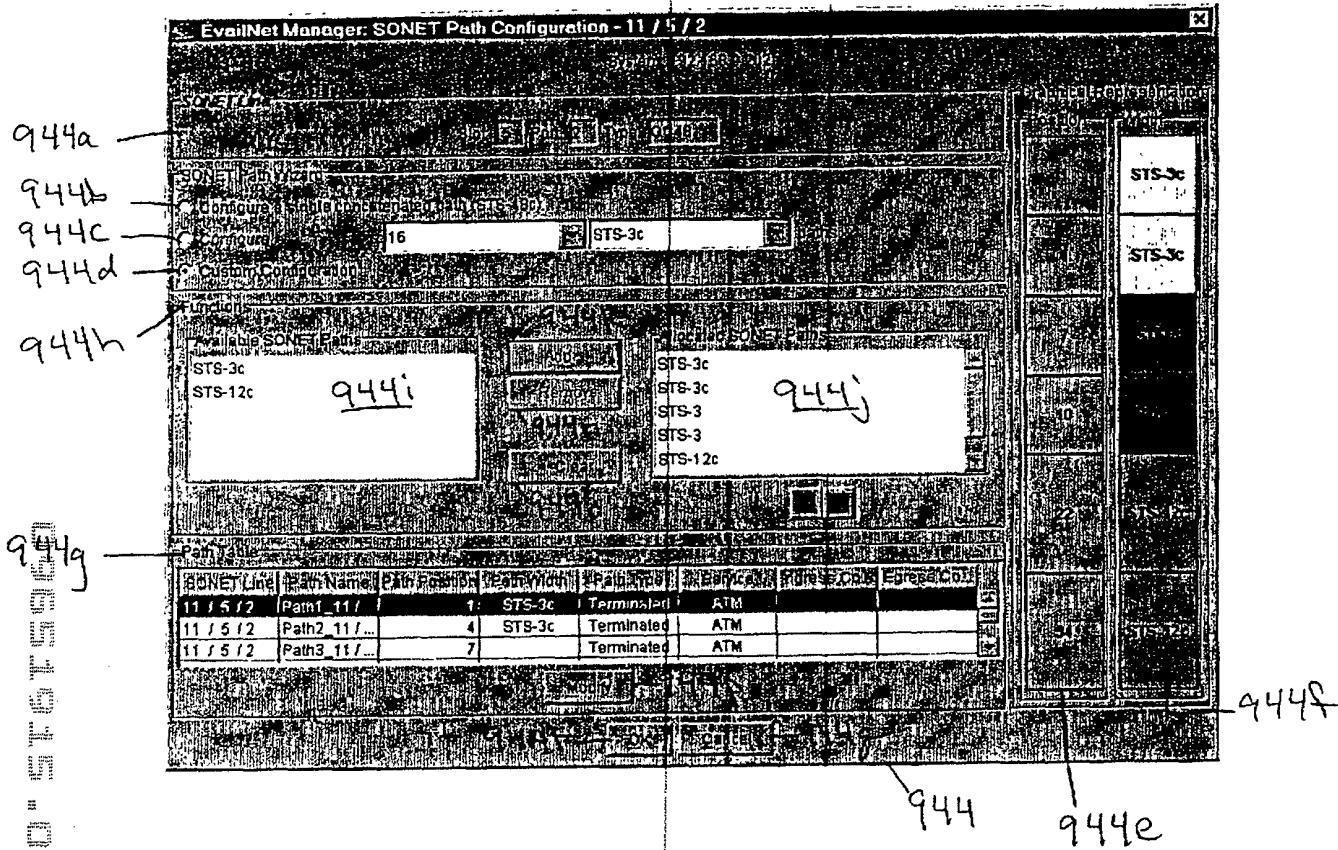


Fig. 5p

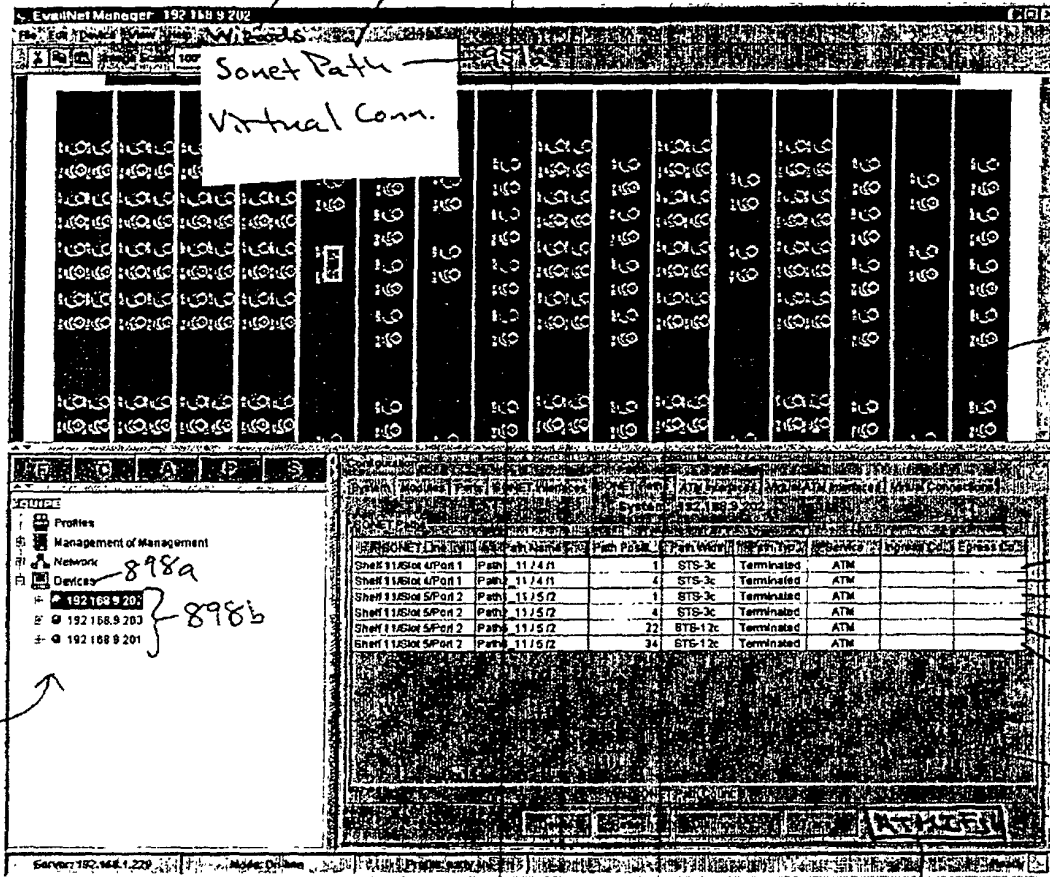


Fig 5g



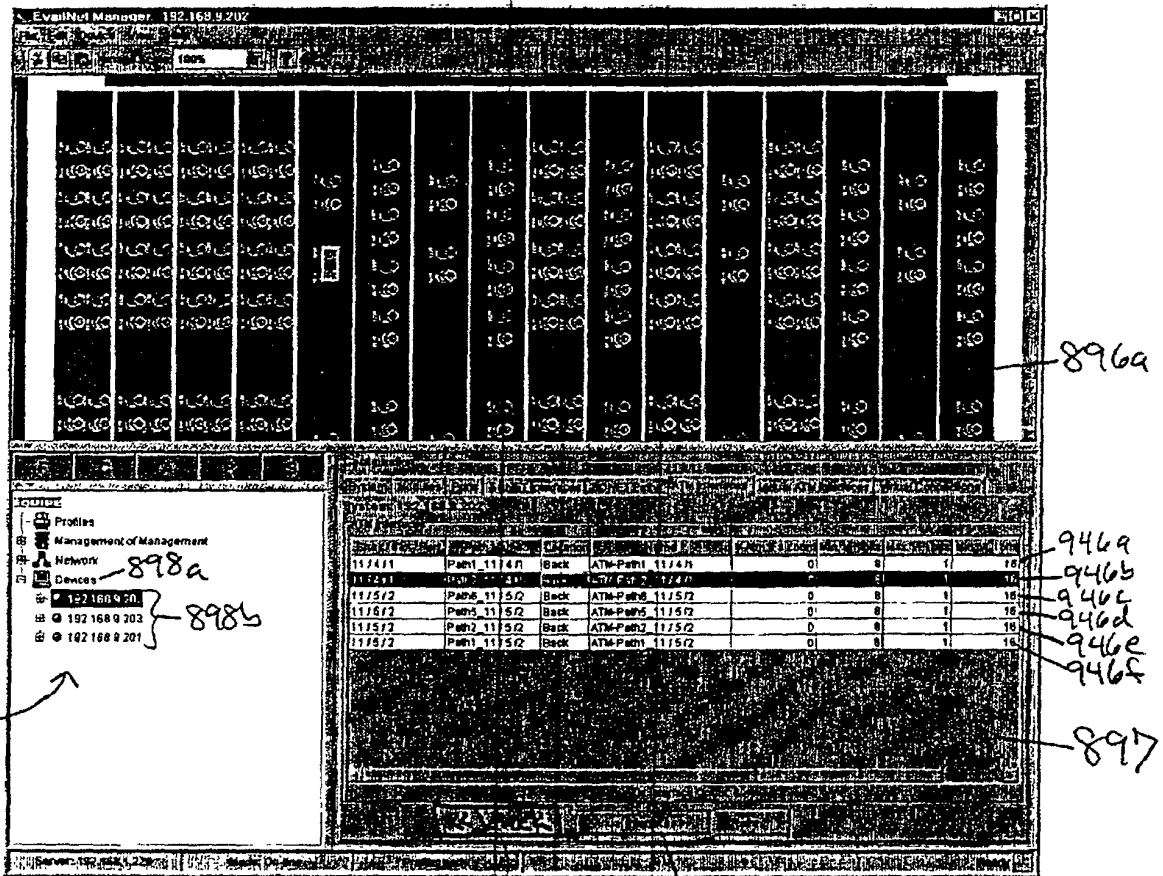


Fig. 5r

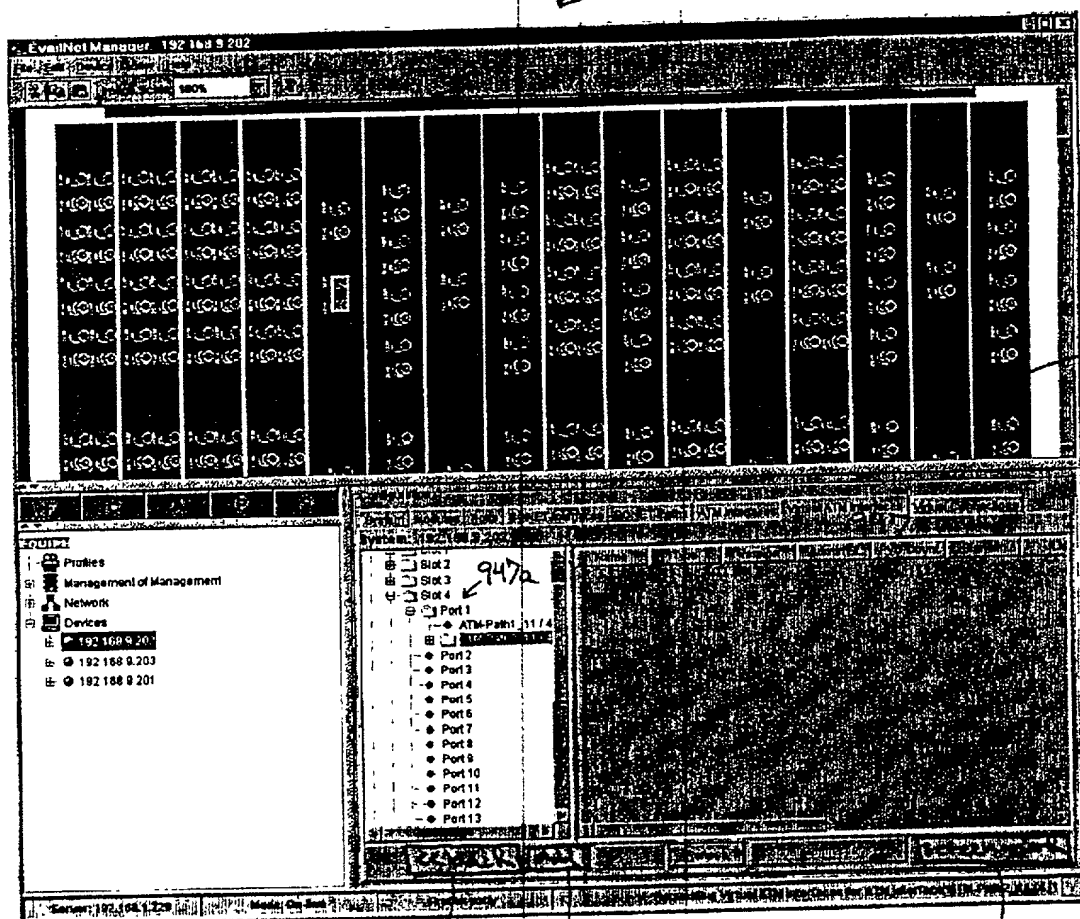
[illegible]

Fig. 5s

Fig. 5+

950

950d

950a

950b

950c

950e

Add V-ATM Interface - 192.168.9.202

Slot/Port: 1/1 Path Name: Path 2\_1

Virtual ATM Interface Parameters:

Name (Alias): test1

Connection type: Direct Link

Version: UNI Network 3.1

Admin Status: Up

OK Cancel

005505.003100

EveilNet Manager 192.168.9.202

192.168.9.202

test1

Direct Link

UNI Network 3.1

Up

947a

947b

947c

Fig. 5u

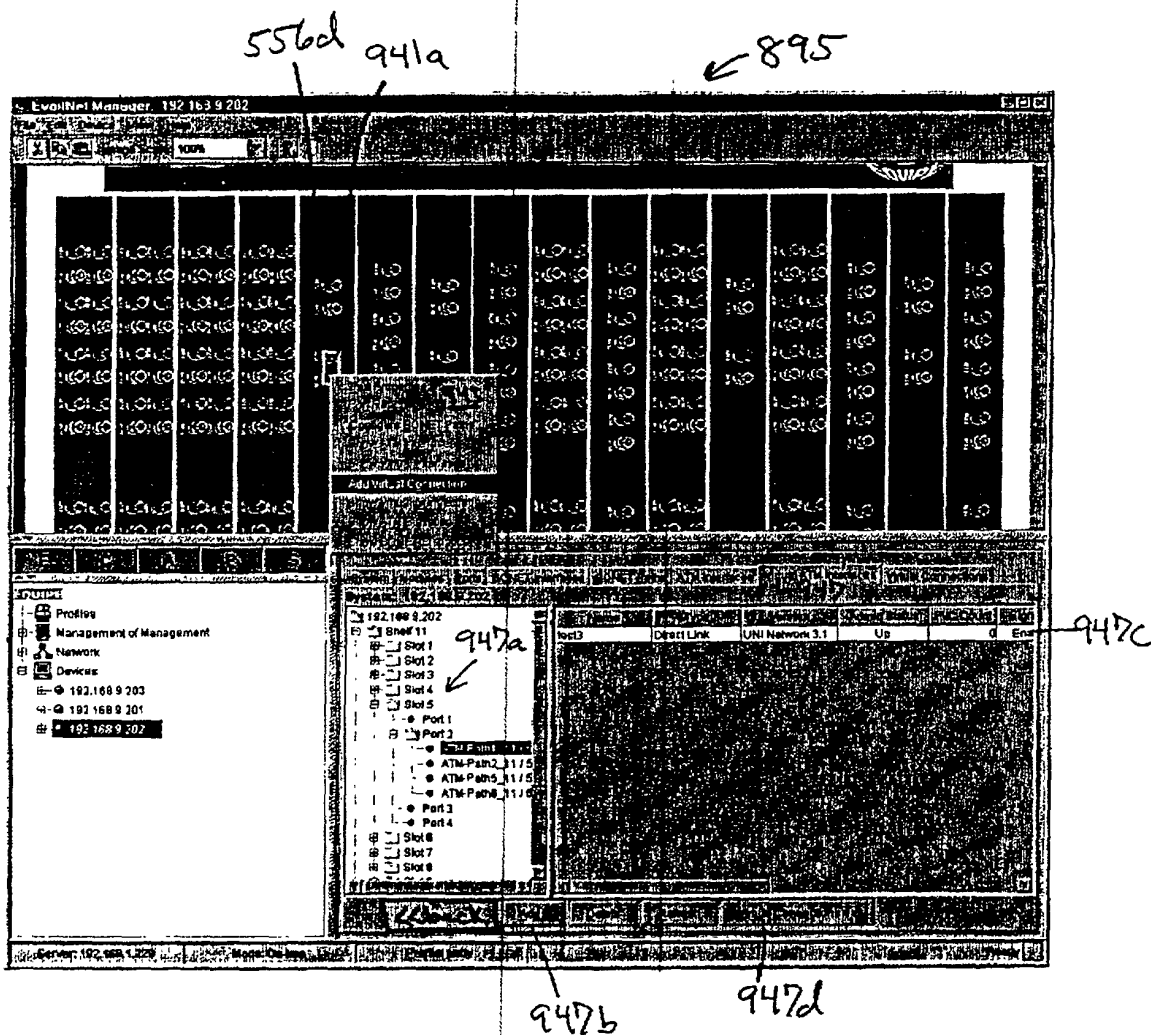
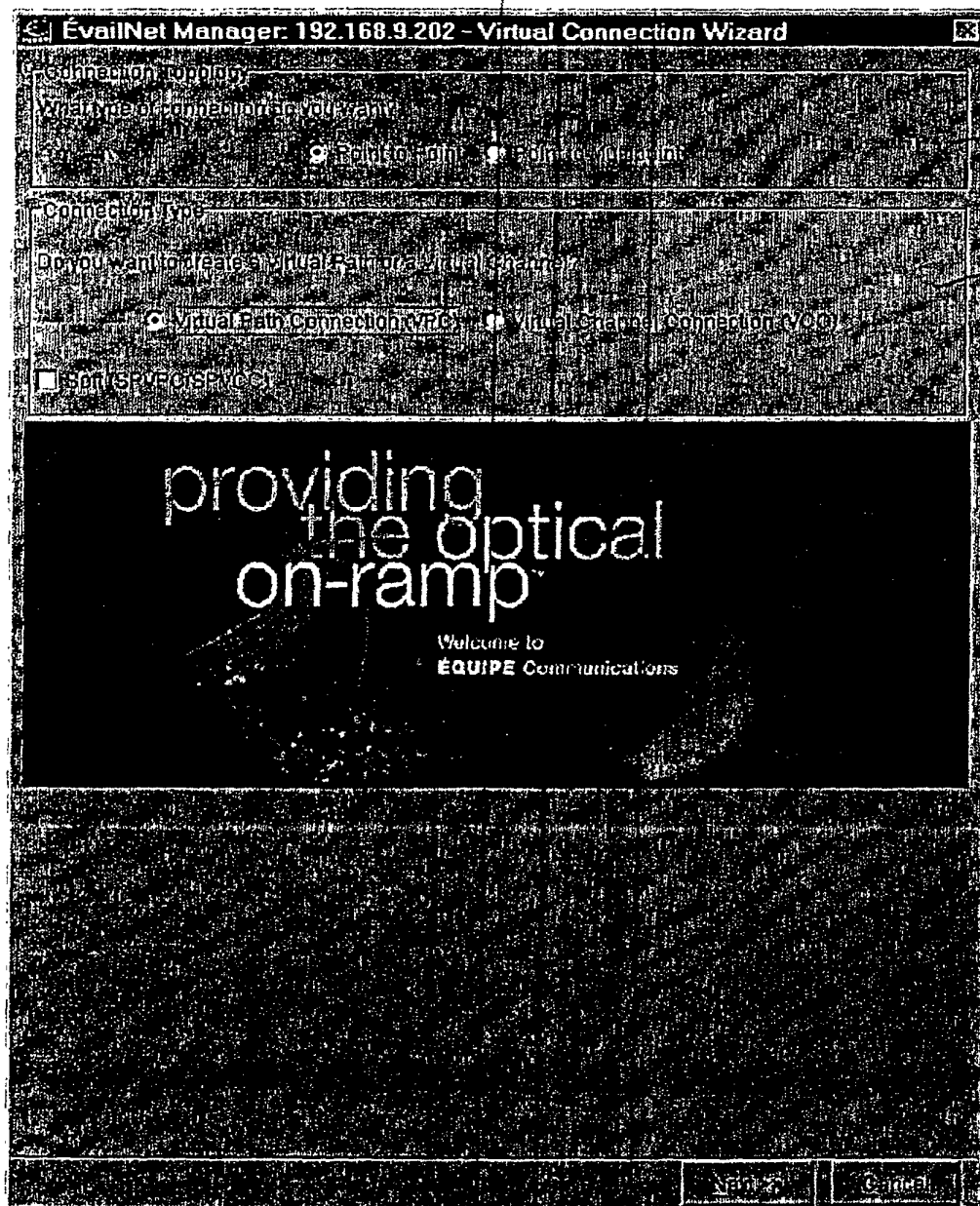


Fig. 5v

0965494E-083100

952



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Fig. 5w

953

953a

953c

953d

953b

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953g

953h

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953j

953k

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953m

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953o

953p

953q

953r

953s

953t

953u

953v

953w

953x

ÉvailNet Manager: 192.168.9.202 - Virtual Connection Wizard

Source: 192.168.9.202 Destination: 192.168.9.11

End Point 1

- Slot 4
  - Port 1
    - ATM-Path1\_11/4/1
      - test1
      - test2
    - Port 2
    - Port 3
    - Port 4

End Point 2

- Slot 3
- Slot 4
- Slot 5
  - Port 1
  - Port 2
    - ATM-Path1\_11/5/2
      - test3
      - ATM-Path2\_11/5/2
      - ATM-Path5\_11/5/2

Connection Parameters

Connection Name: test

Admin Status: Up

Customer Name: Walmart

End Point 1 Parameters

VP: 953i

VCI: 953m

Transmit Traffic Descriptor: VBR-high

Receive Traffic Descriptor: VBR-high

Use the same Traffic Descriptor for both Transmit and Receive

End Point 2 Parameters

VP: 953j

VCI: 953n

Transmit Traffic Descriptor: VBR-high

Receive Traffic Descriptor: VBR-high

Use the same Traffic Descriptor for both Transmit and Receive

Buttons: Back, Finish, Cancel

956

**New Traffic Descriptor**

Name:

QoS Class:  ▼

Type:  ▼

Fig. 5Y

895

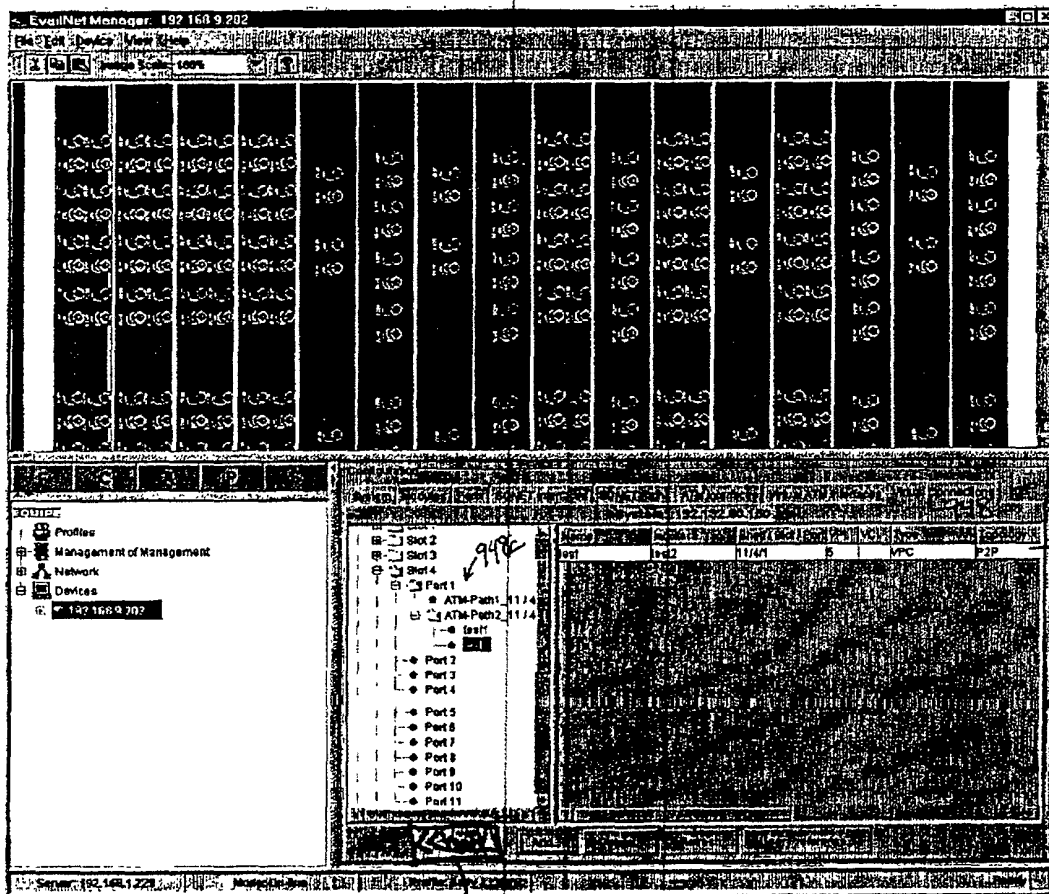
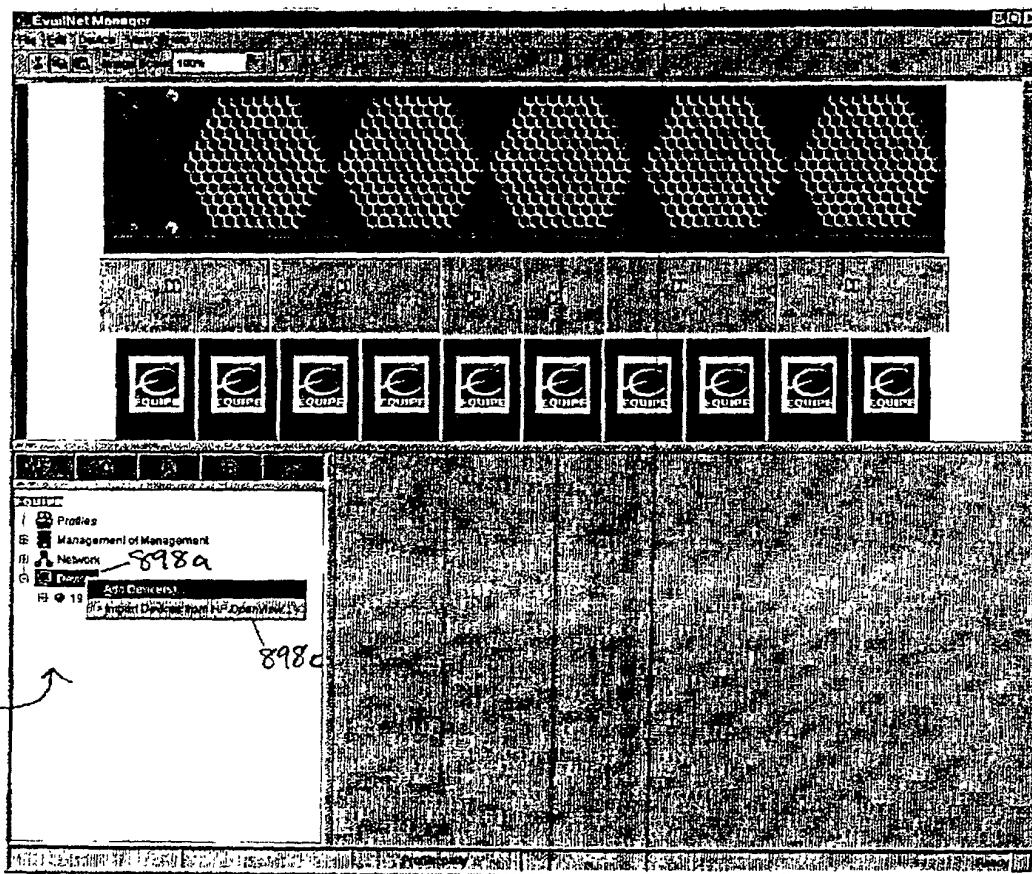


Fig. 52



895



0061910.03100

Fig. 6a

Fig. 6b

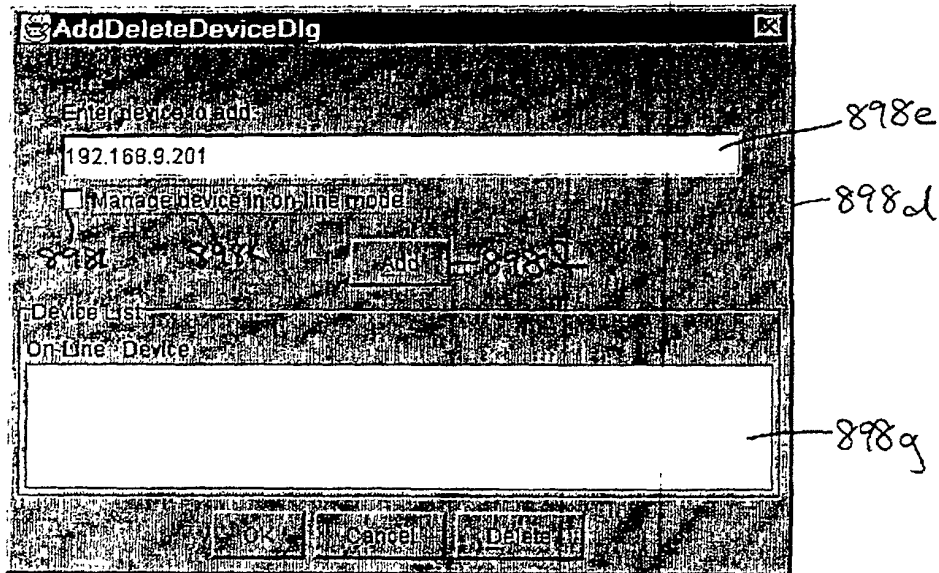
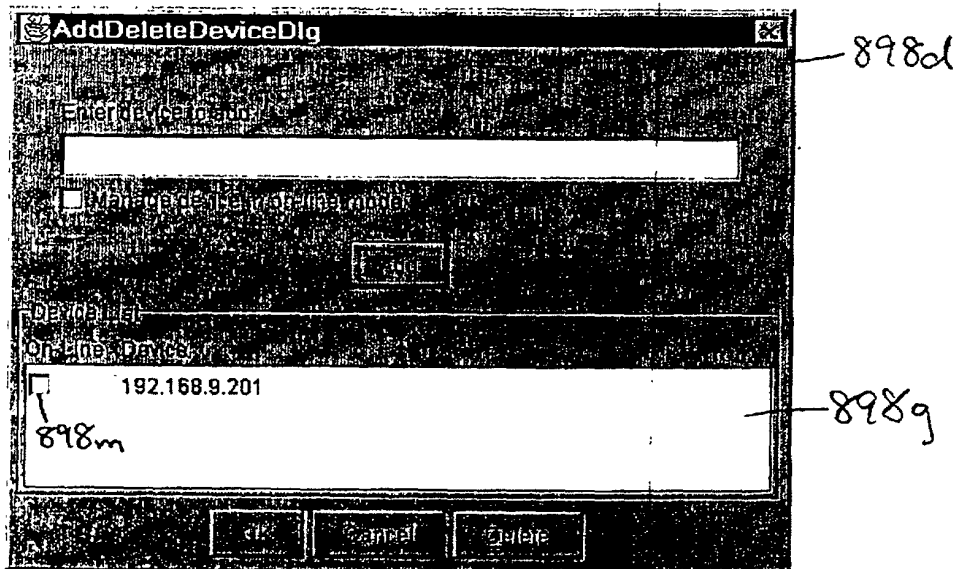
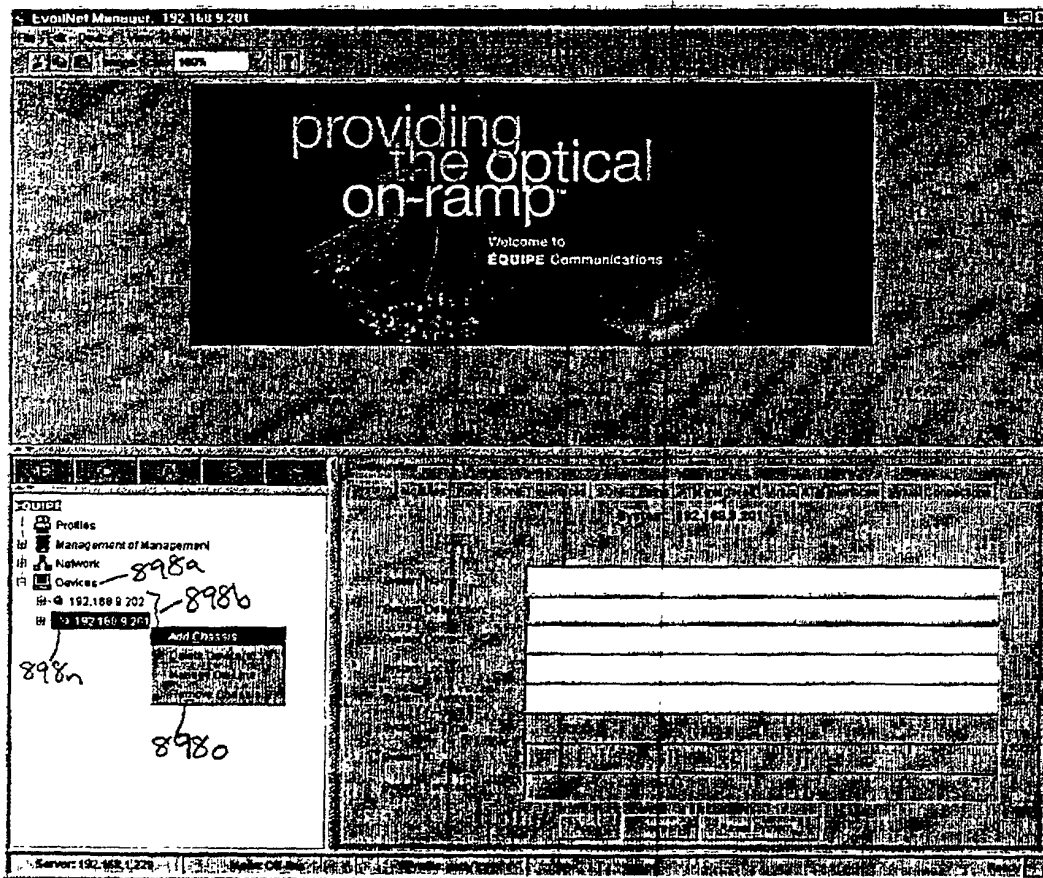


Fig. 6c



007500" 5757560

895



09664948 083400

Fig. 6d

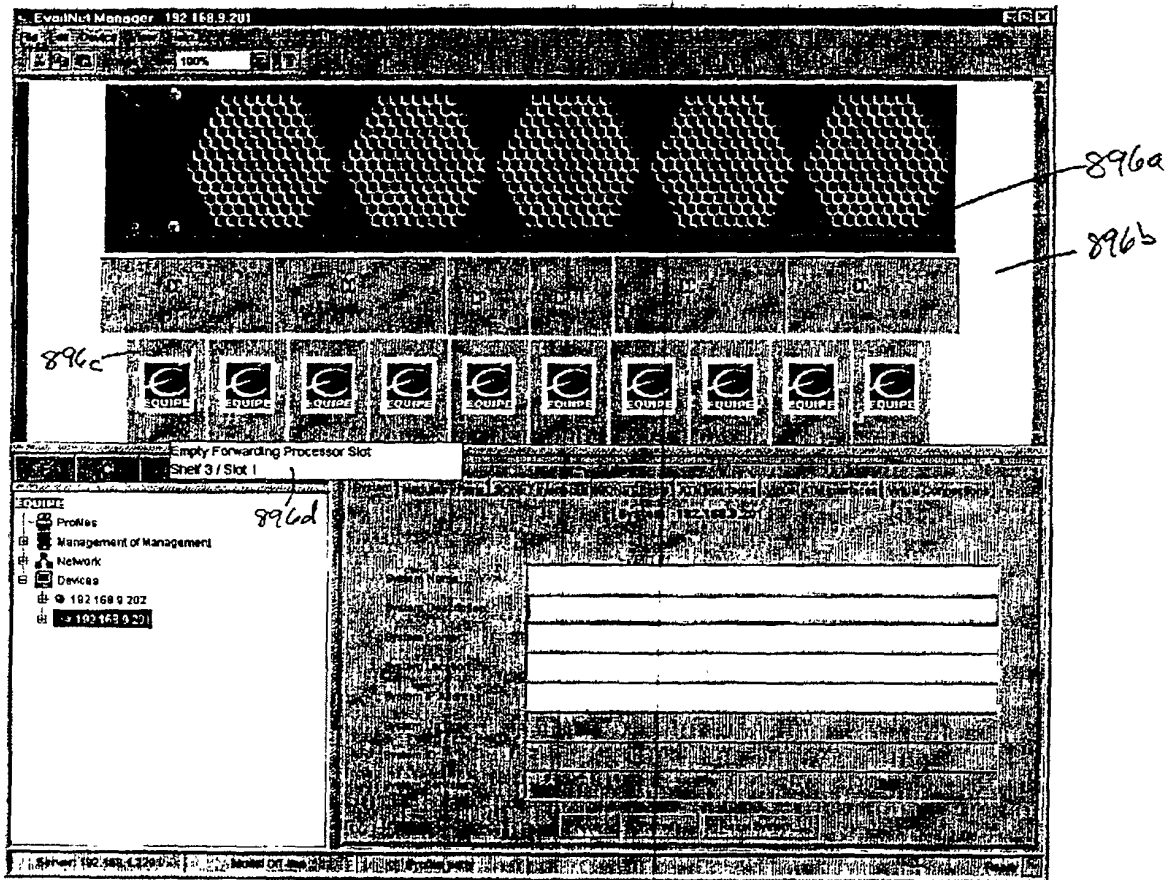


Fig. 6e

0954543.083400

895

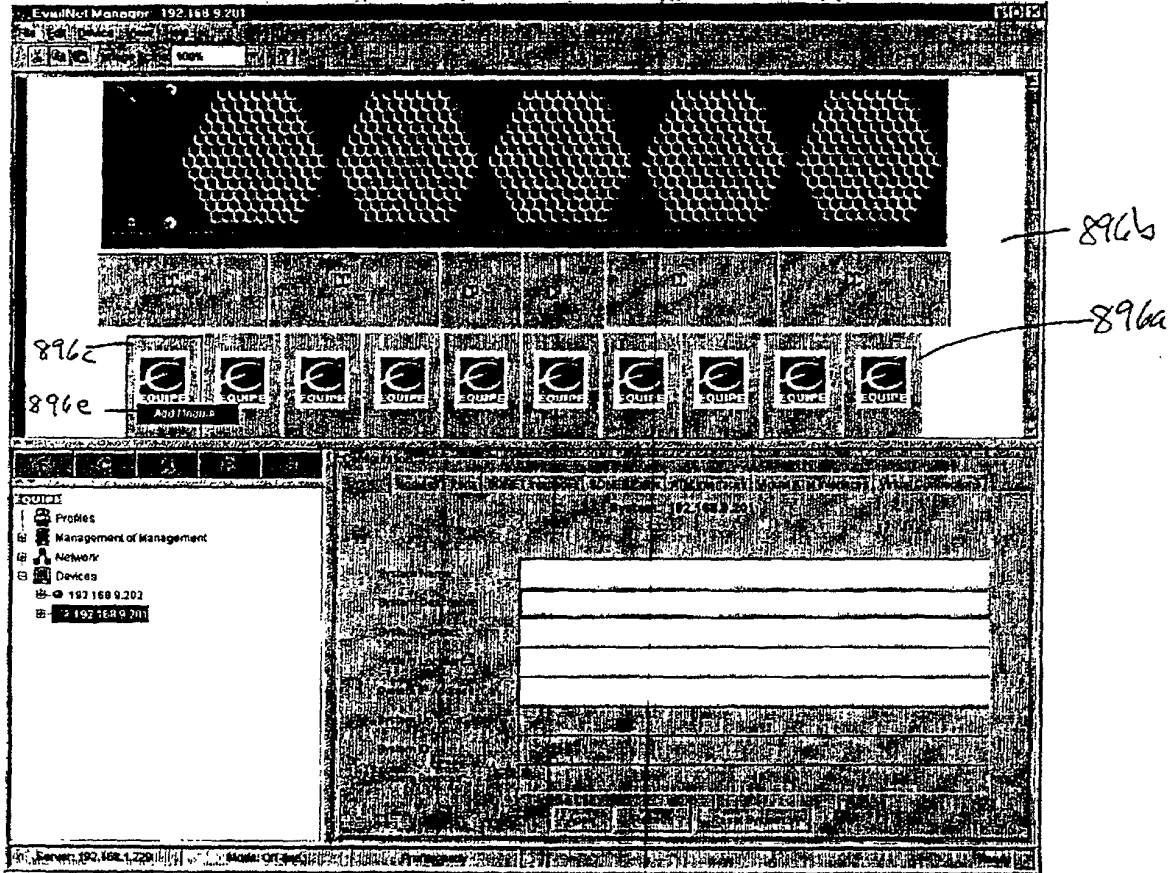
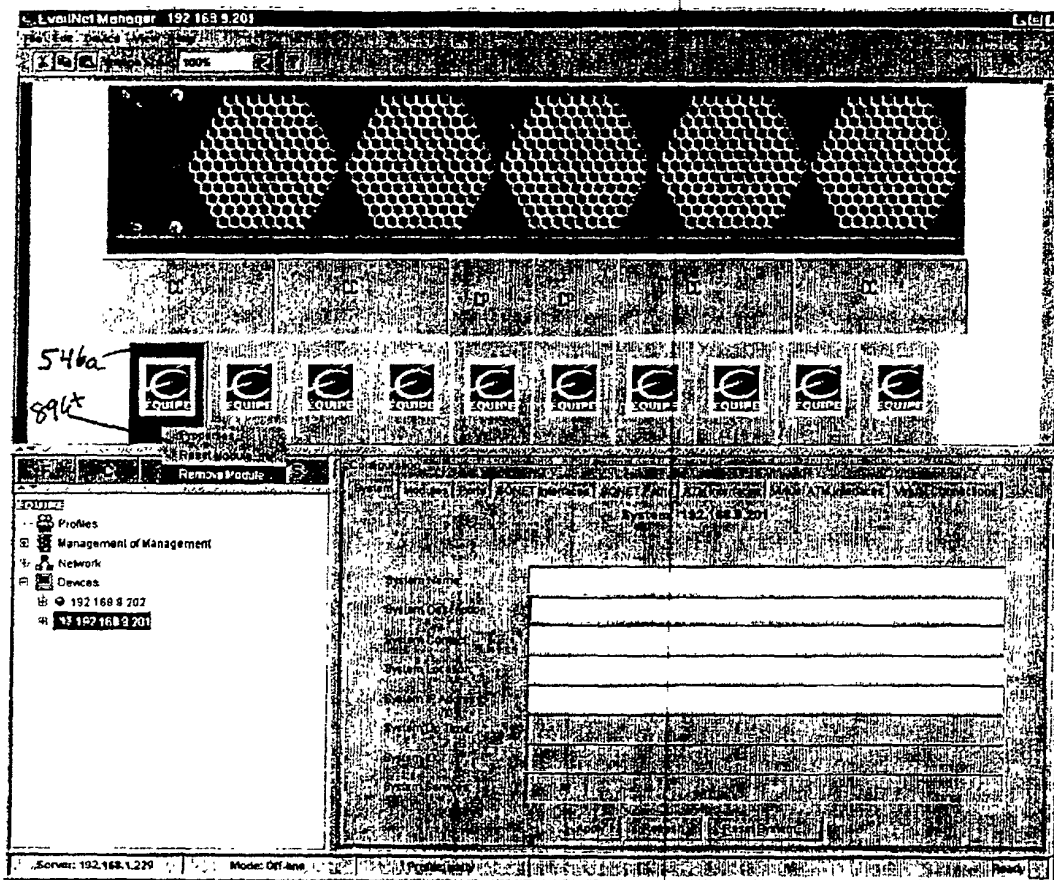


Fig. 6f

0065105, 003100

895



09051915.083100

Fig. 69

895

896f

00T580"5T6T560

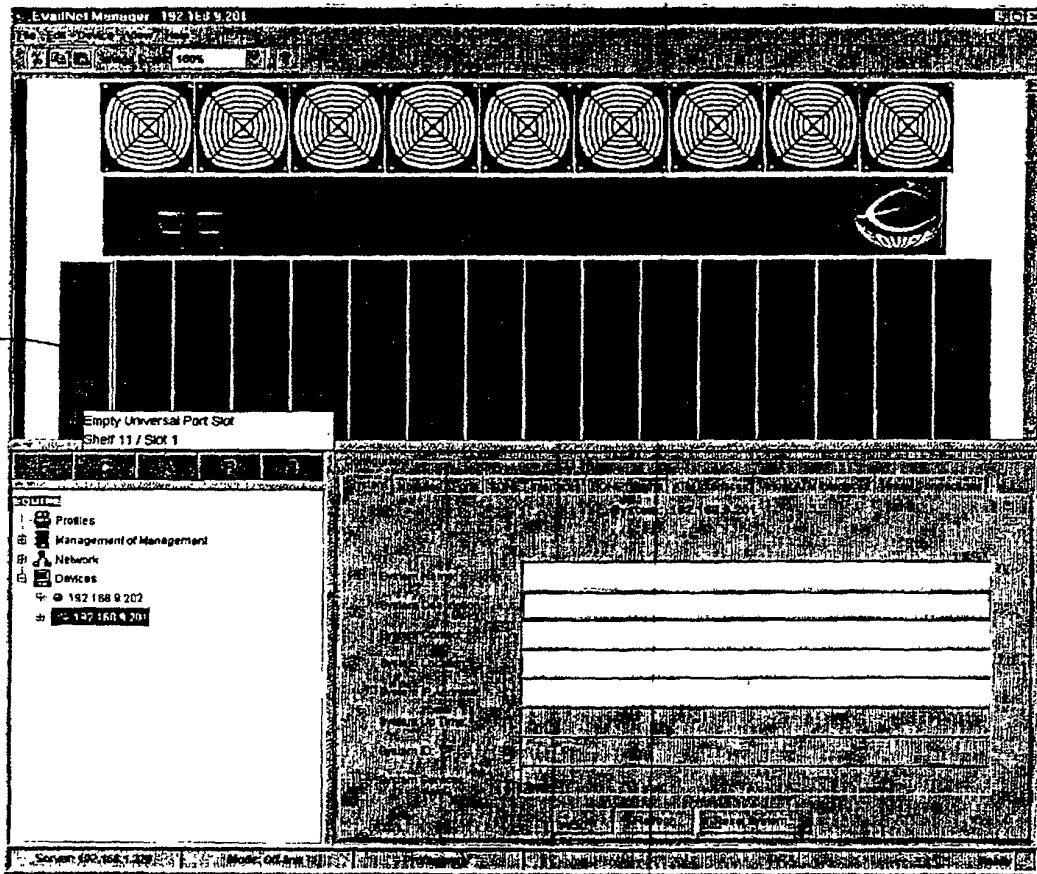


Fig.6h

895

896f

896g

007E0"5T6T0050

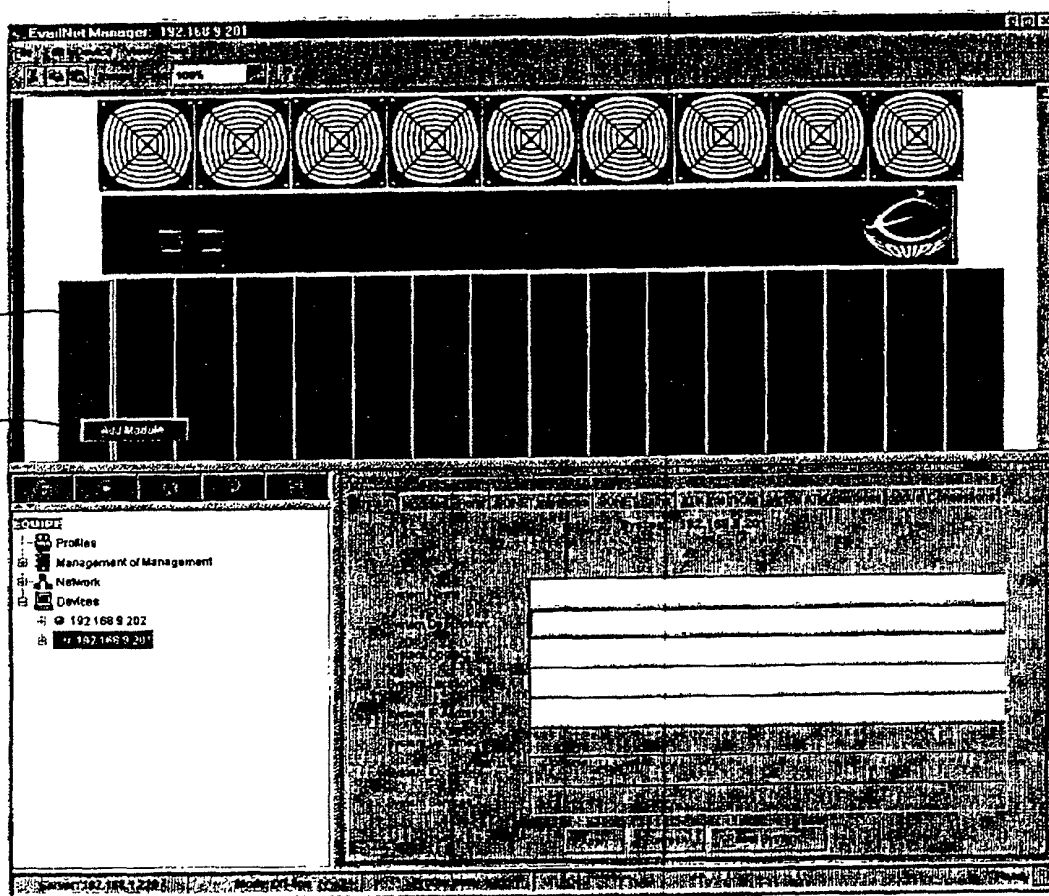


Fig. 6i





895

556i

556h

00T60"5T6T960

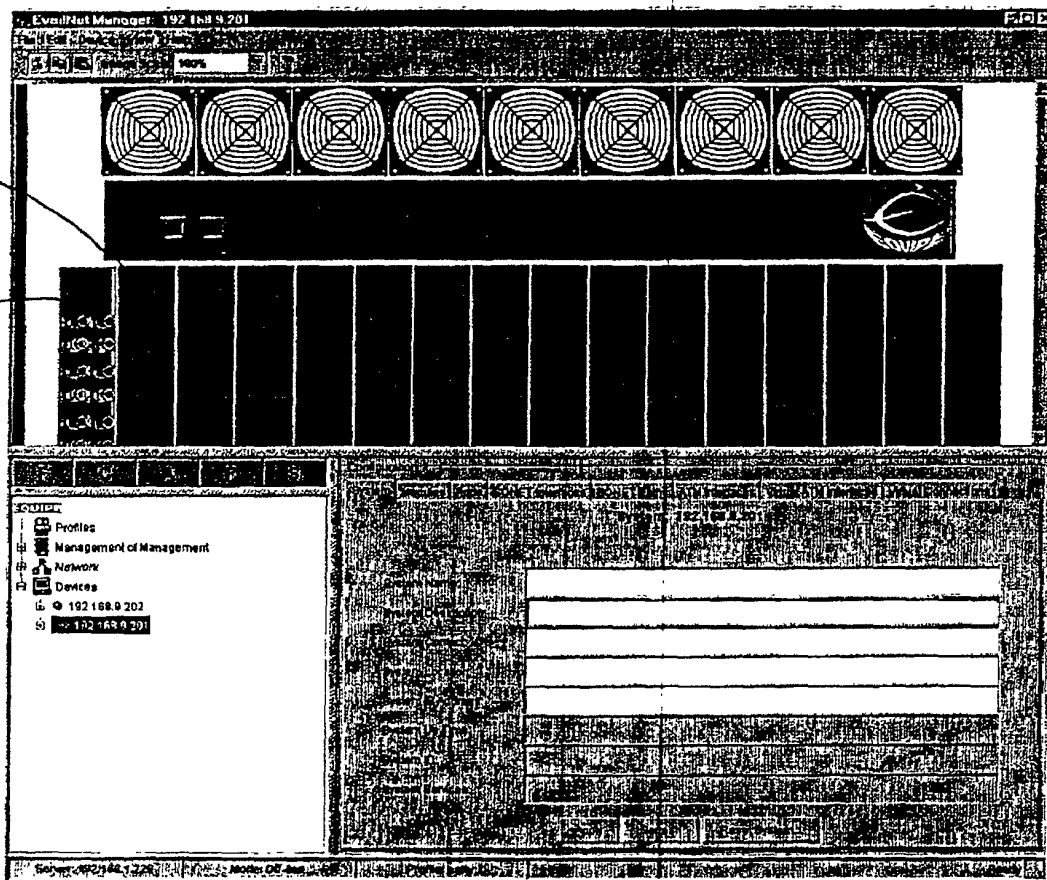
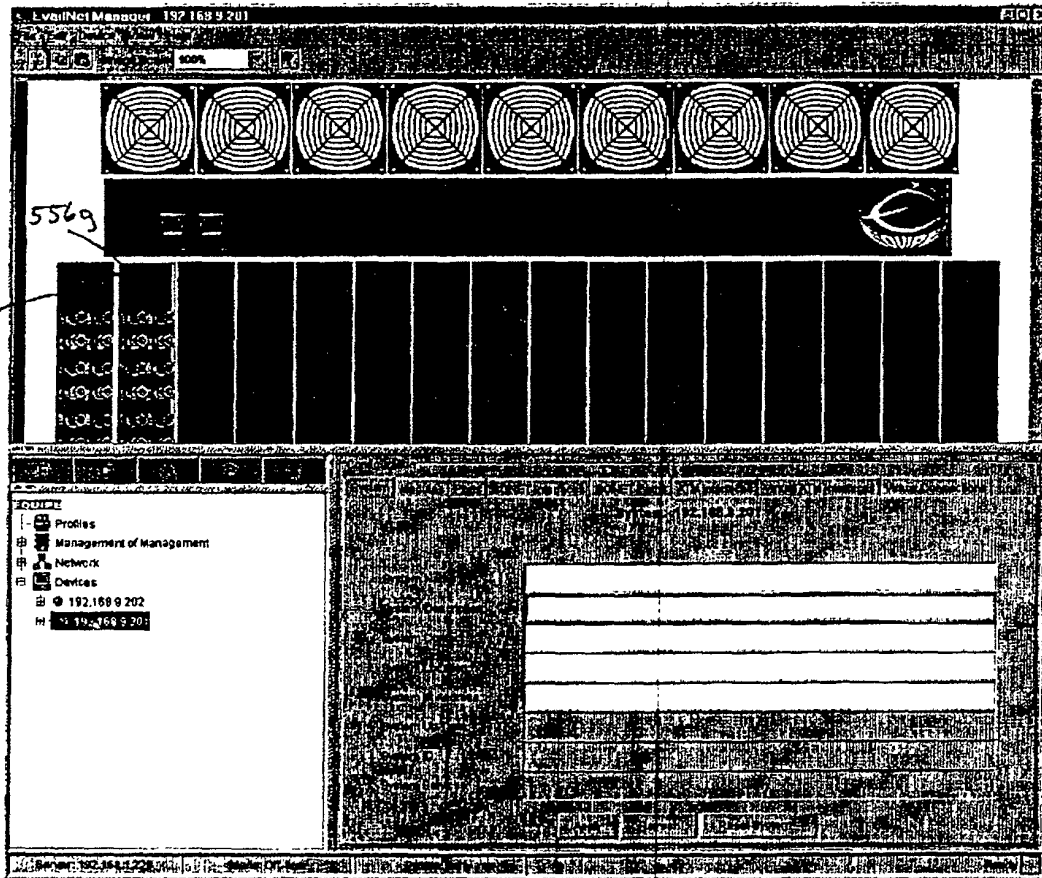


Fig. 6L

895



09691935.083400

Fig.6m

895

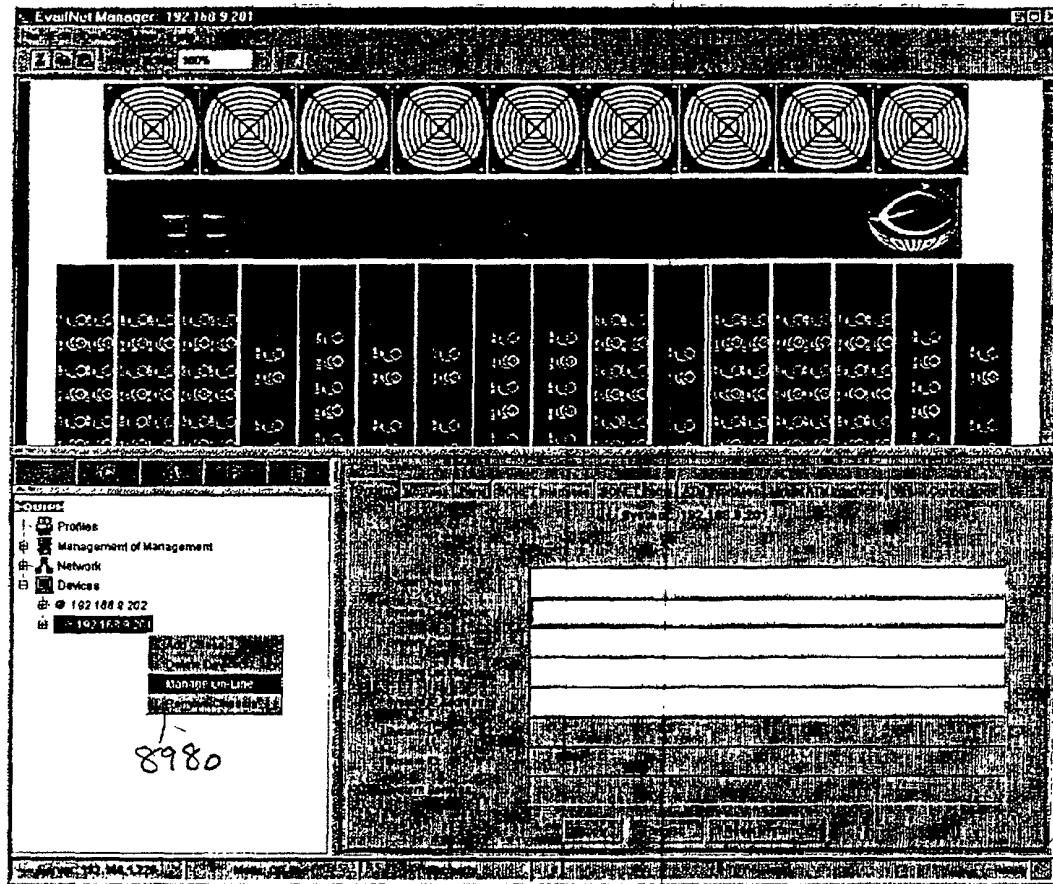


Fig. 6n

895

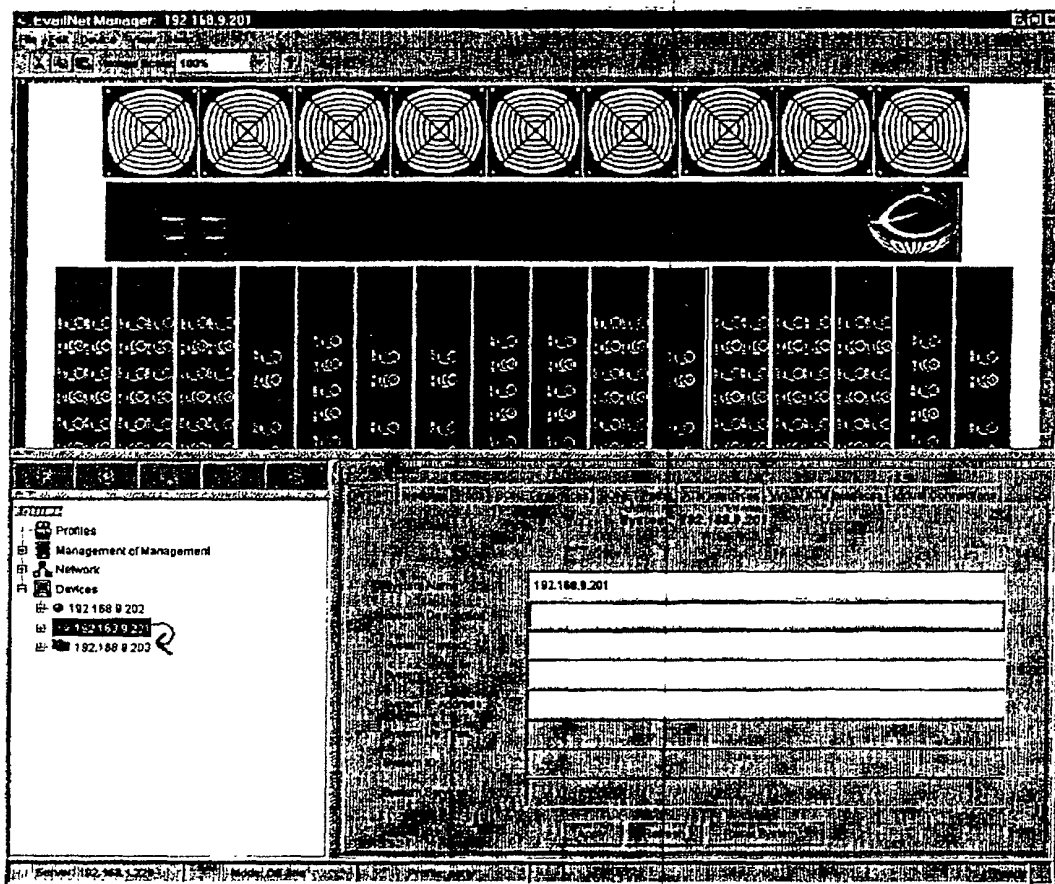


Fig. 60

895

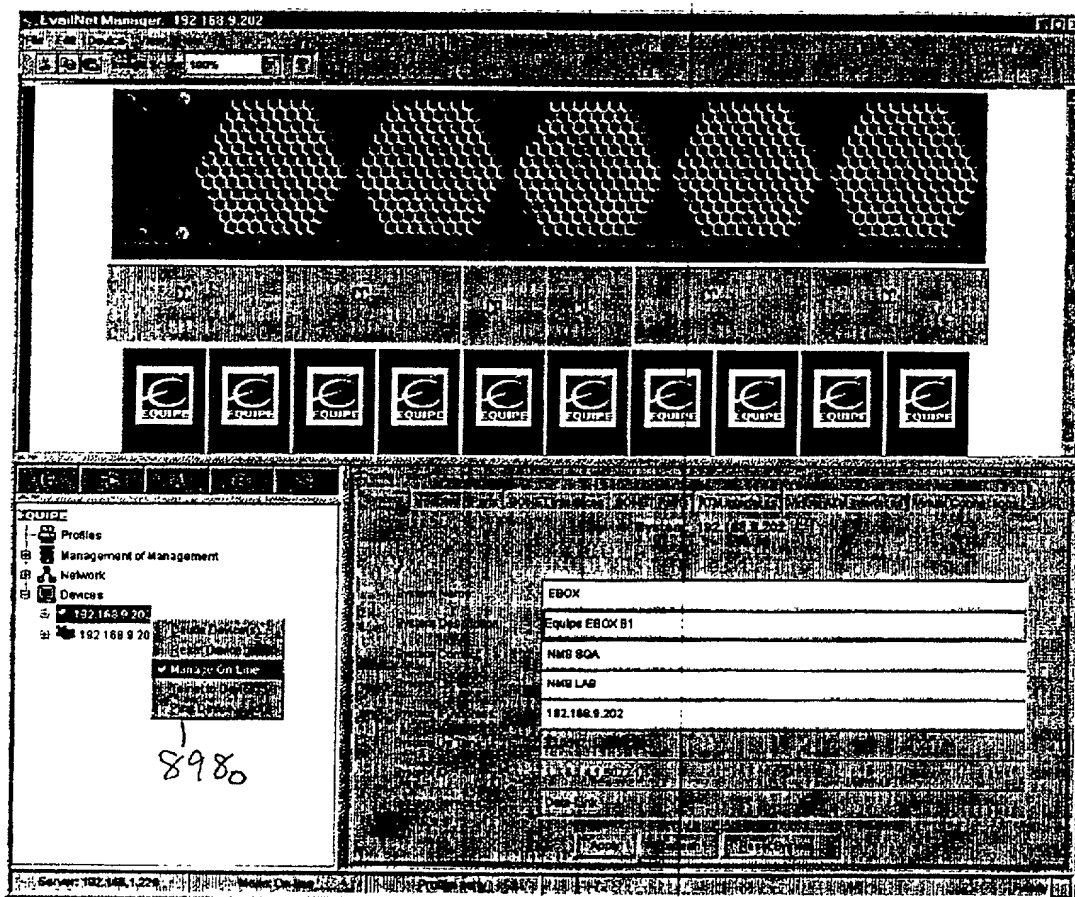


Fig. 6p

00T680" 6T6T5960

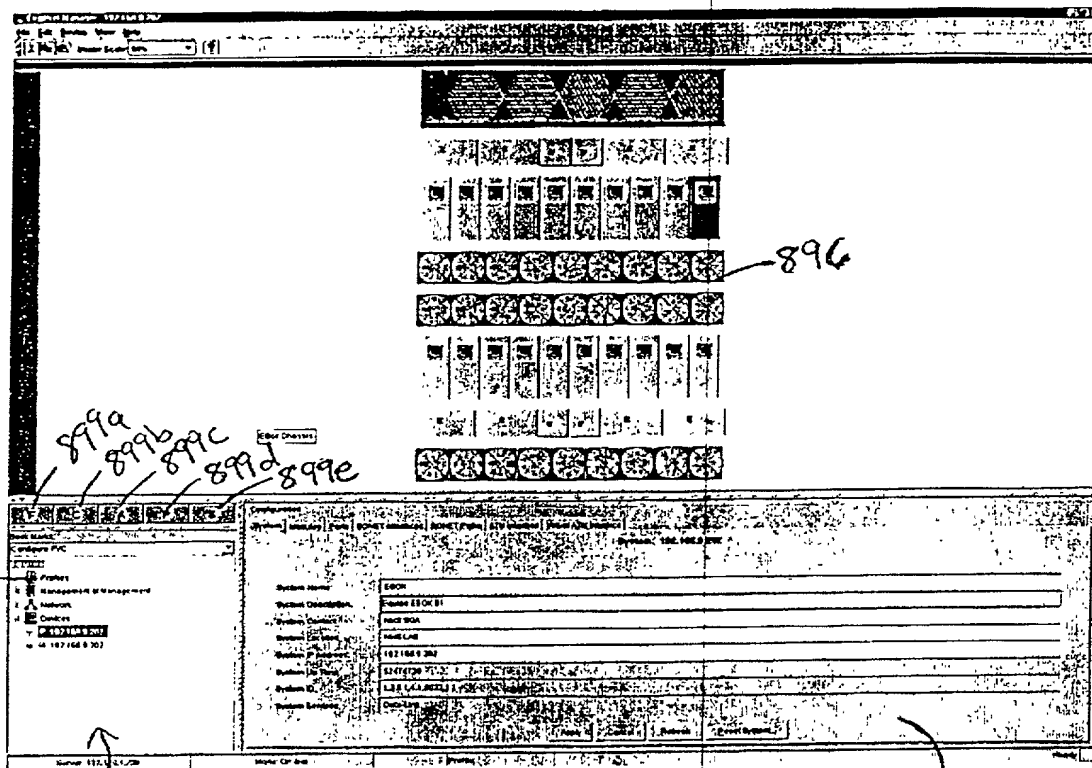


Fig. 7a

EvaiNet Manager: Fault - Event Summary			
System: 192.168.65.160			
System	Event	Event Number	Description
1.1.55.6	Fan OverTemp	44	"Fan marginally functioning"
1.1.55.7	New Board Ins...	75	"New board inserted"
OK			

Fig. 7b

00FEE0"ST6T5960



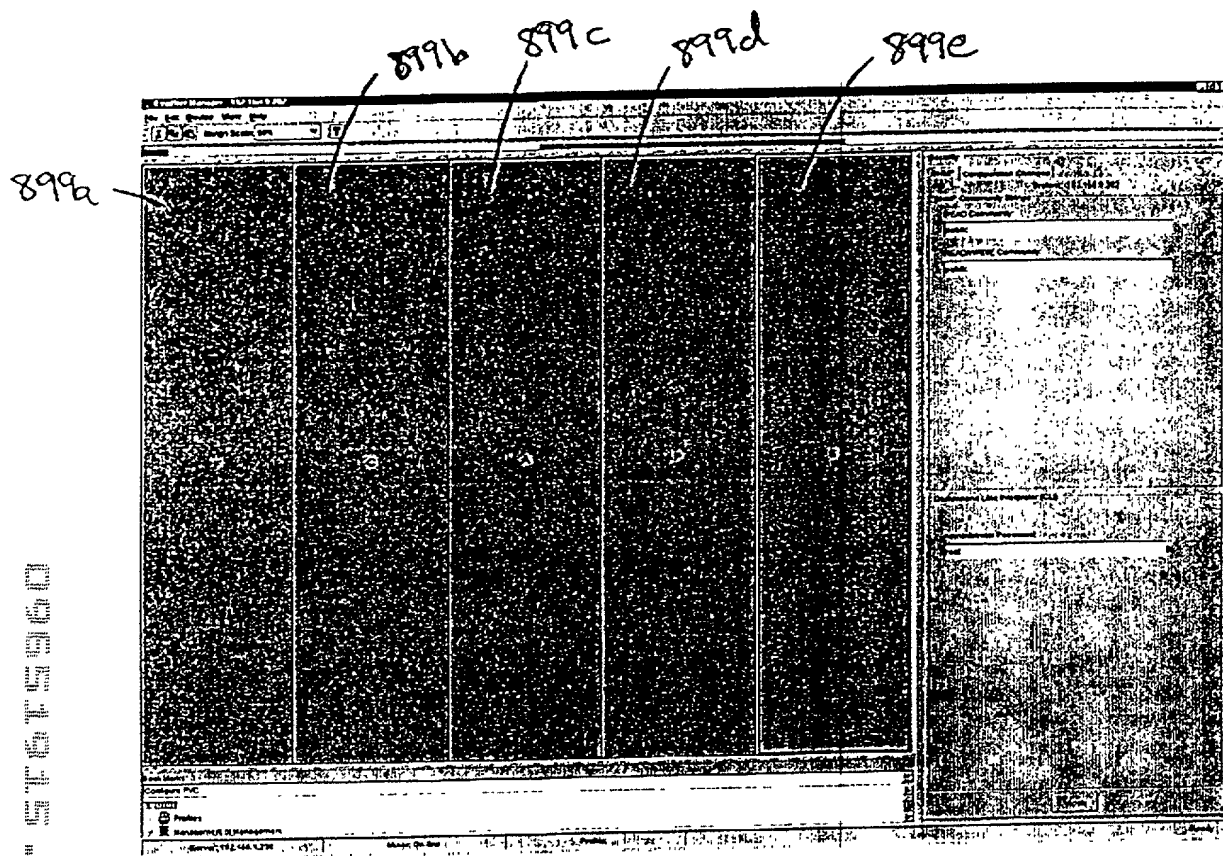


Fig.7c

Name	Description	Security Level	Timeout	Primary Server	Secondary Server
Joe	Joe Whitehouse	Admin	15	192.168.1.32	192.168.1.37
Wayne	Wayne Arena	Provisioner	15	TeamServer1:192.168...	TeamServer2:192.168.1.32

Fig. 7d

Parameter	Unit	Value
Temperature	°C	25.0
Humidity	%	65.0
Pressure	hPa	1013.25
Wind Speed	m/s	1.5
Wind Direction	°	135
Cloud Cover	%	10
Visibility	km	10.0
Relative Humidity	%	65.0
Dew Point	°C	18.0
Sea Level Pressure	hPa	1013.25
Altitude	m	0.0
Latitude	°N	40.71
Longitude	°W	84.01
Time	HH:MM:SS	12:00:00
Date	MM/DD/YYYY	01/01/2020
Location	City, State, Country	New York, NY, USA
Station ID	String	NYC001
Observer	String	John Doe
Instrument	String	Model X-100
Calibration	String	Valid
Notes	Text	Clear sky, light breeze.

Fig. 7e

907

General

Username:

Kevin

Description:

Kevin Snow user account

Group Name:

Equipe

Group Level Access:

Password:

\*\*\*\*\*

Confirm Password:

\*\*\*\*\*

Policies

☒ User Cannot Change Password

☐ Account Disabled

☒ User Can Add Devices

User Session Timeout:

15

Minutes

Servers

Primary Server:

192.168.1.220

Primary Server Port:

6500

Secondary Server:

192.168.1.221

Secondary Server Port:

6503

Devices

Device	READ	READ/WRITE	Retry	Timeout		
192.168.9.202	public	equipe	3	5		
192.168.9.205	public	equipe	3	5		
192.168.9.216	public	equipe	3	5		

Add

Delete

OK

Cancel

908a

908e

908f

908d

908b

908c

908h

908i

908j

908k

908l

908n

908m

908o

908p

908q

908r

908s

908t

908u

908v

908w

908x

908y

908z

Fig. 7f

GeneralPoliciesServers**Devices**

Username:

Kevin

Description:

Kevin Snow user account

Customer Name:

Equipe

Group Level Access:

Password:

\*\*\*\*\*

Confirm Password:

\*\*\*\*\*

OK

Cancel

GeneralPoliciesServers**Devices**

☒ User Cannot Change Password

☐ Account Disabled

☒ User Can Add Devices

User Session Timeout:

15

Minutes

OK

Cancel

Fig. 7g

00551915.083400



909

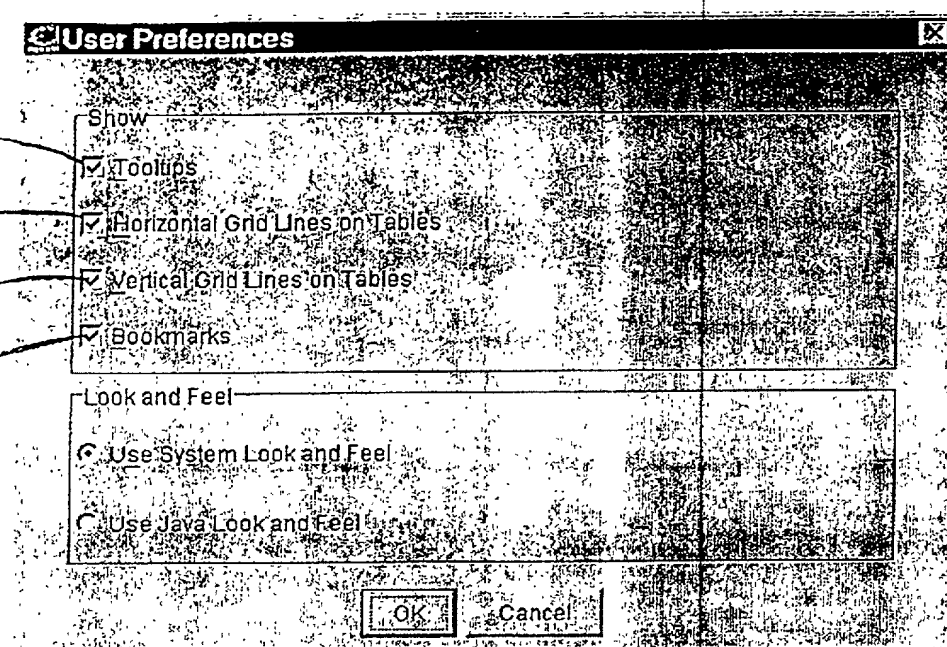


Fig. 76



CARD TABLE

PID	CWD TYPE	VERSION NO.	SLOT NO.	...
16 a — 500	0XF002	3	1	
16 b — 501	0XF002	4	2	
...	...	...	...	...
16 e — 505	0X6002	1	5	
...	...	...	...	...
16 n — 513	0XF002	1	12	
...	...	...	...	...

FIG. 8b

09051915.000000



PORT TABLE

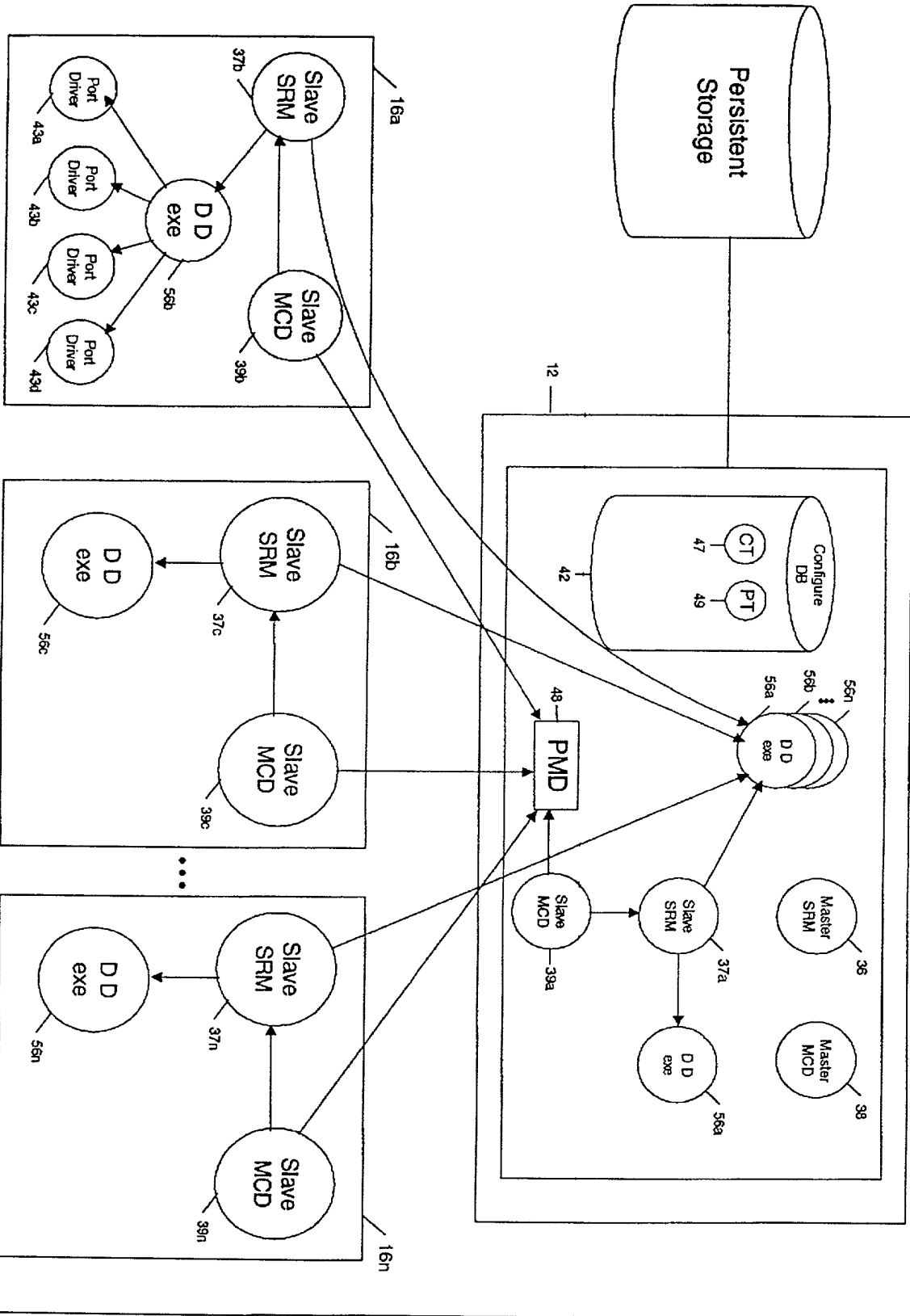
49						
PID		PORT TYPE	VERSION NO.	SLOT NO.	...	
44a	1500	00620	1	1		
44b	1501	00620	1	1		
44c	1502	00620	1	1		
44d	1503	00620	1	1		
44a	1504	00820				
46a	...	...	...	...	...	...
	1600	00620	1	8		
	...	...	...	...	...	...

FIG. 8c

09634915, 0829100

FIG. 9a

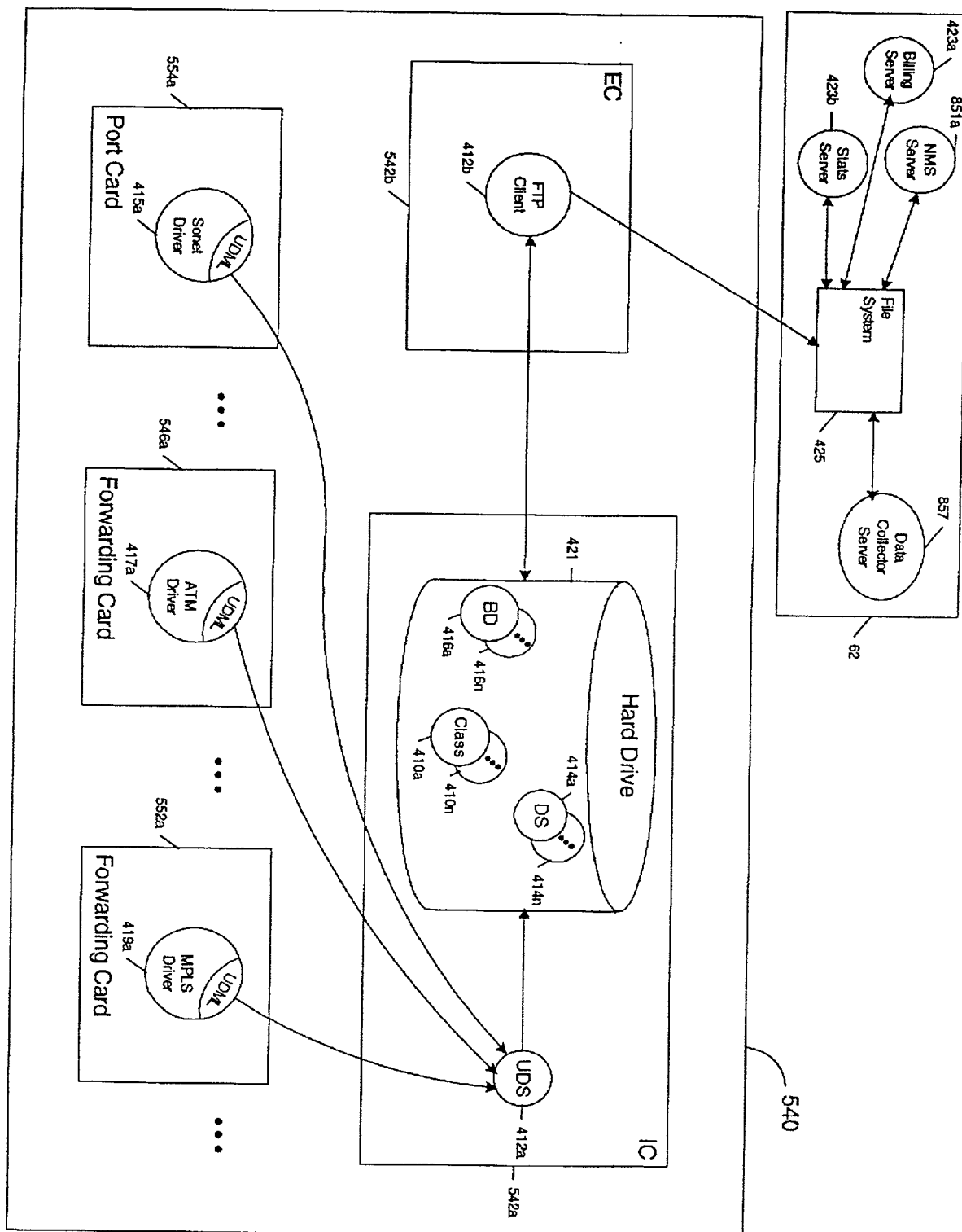
10



DocId:315083100



Fig. 9c



09654945, 000100

FIG. 10

Service Endpoint Table 76

	Service Endpoint #	Port PID
78	1	1500
80	2	1501
82	3	1501
84	4	1501
86	5	1502
88	6	1502
90	7	1503
92	8	1503
94	9	1503
168	10	1502
	⋮	⋮

FIG. 11a

Logical to Physical Card Table 100

	98 LID	102 Primary PID	104 Back-up PID
106	30	500	513
109	31	501	513
	⋮	⋮	⋮

FIG. 11b

Logical to Physical Port Table 101

	98 LID	102 Primary PID	104 Back-up PID
107	40	1500	1600
	⋮	⋮	⋮

FIG. 12

ATM Group Table 108

Group #	Card LID	...
1	30	
2	30	
3	30	
4	30	

FIG. 13

ATM Interface Table 114

ATM IF	ATM Group	SE	...
1	1	1	
2	1	1	
3	1	1	
4	2	2	
5	2	3	
6	2	4	
⋮	⋮	⋮	⋮
12	3	10	
⋮	⋮	⋮	⋮

FIG. 14

Software Load Record 128a

130	Control Shim	LID	132
134	atm-ctrl.exe	30	

FIG. 15

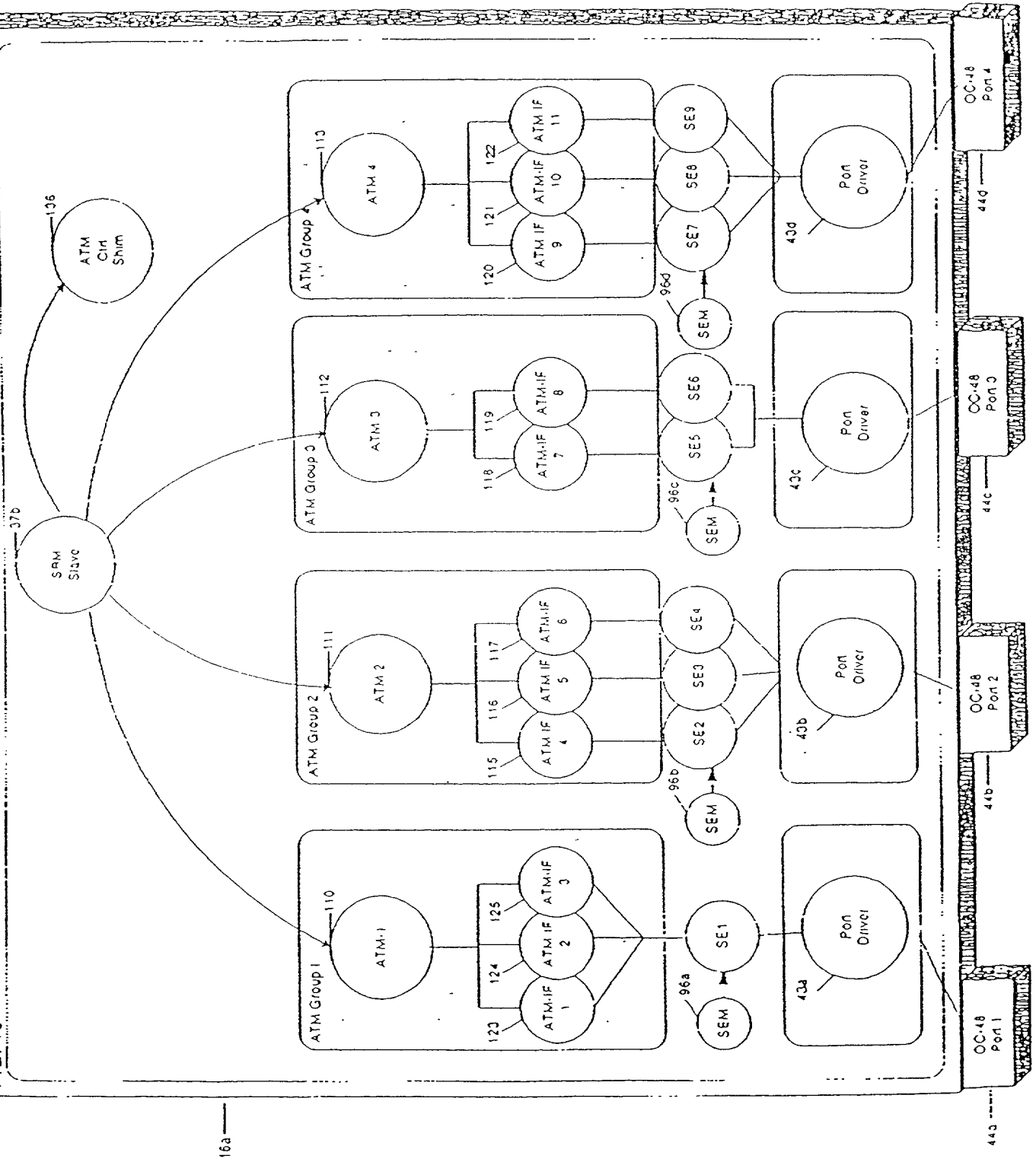


FIG. 16a

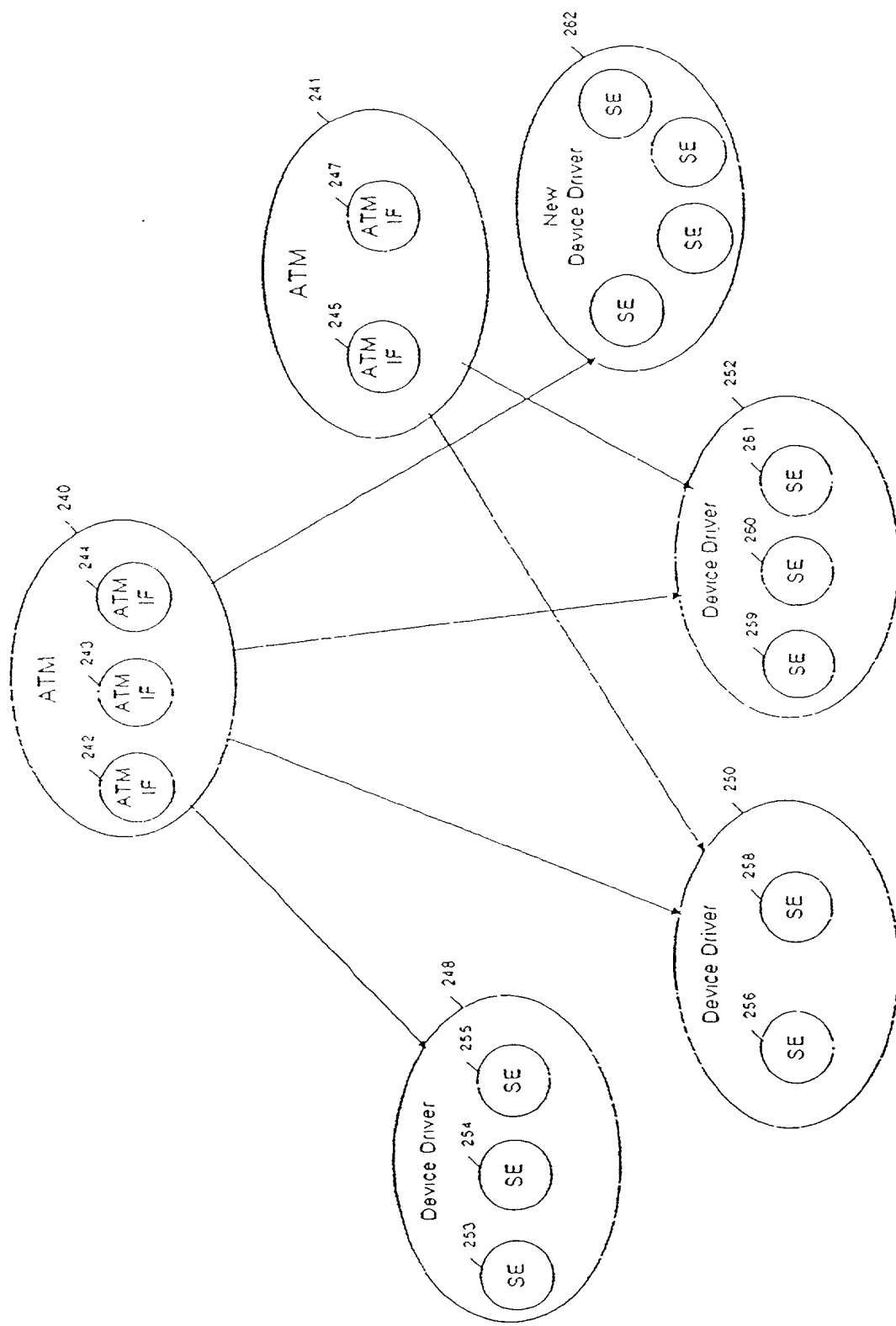




FIG. 16b

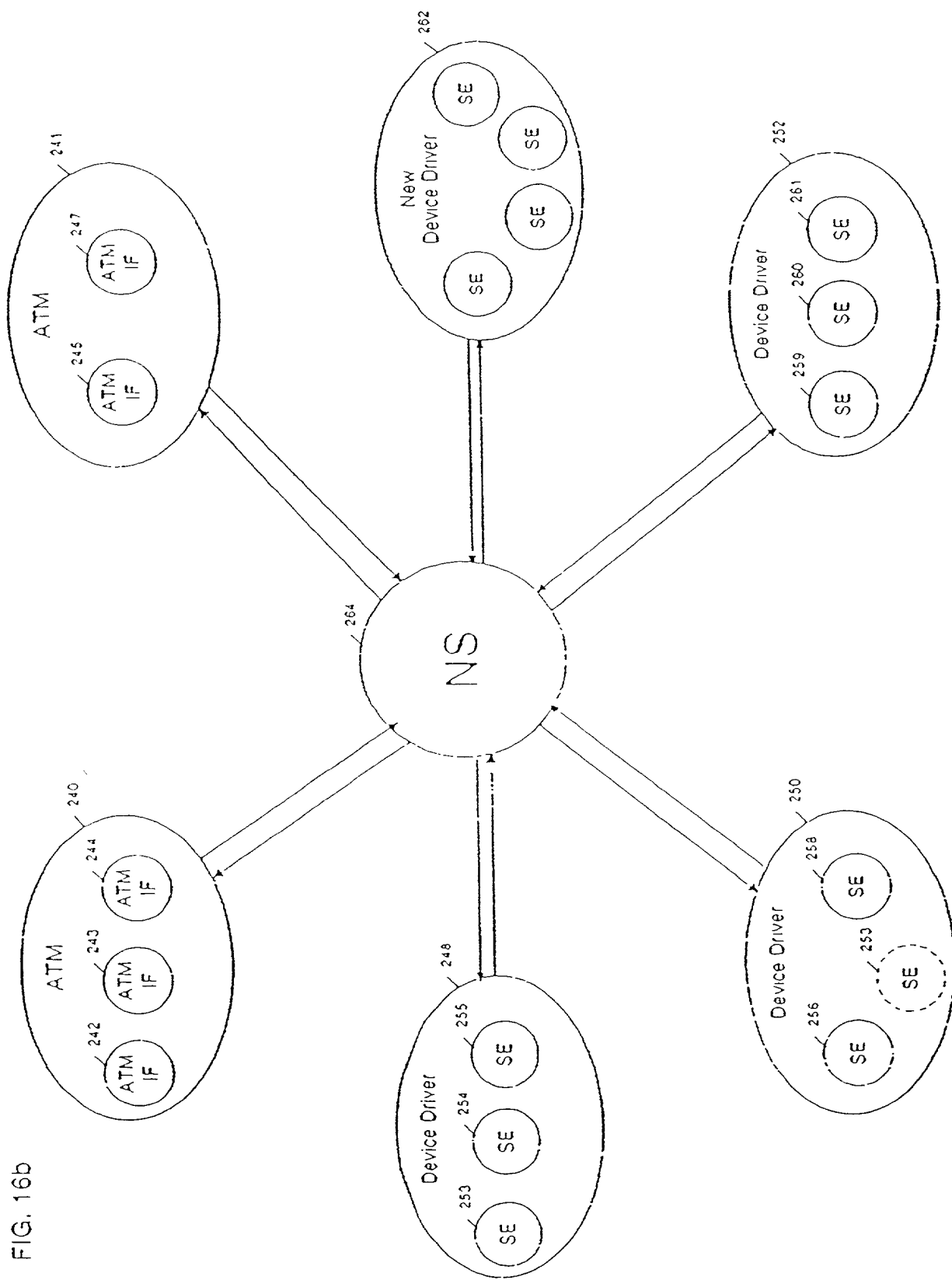
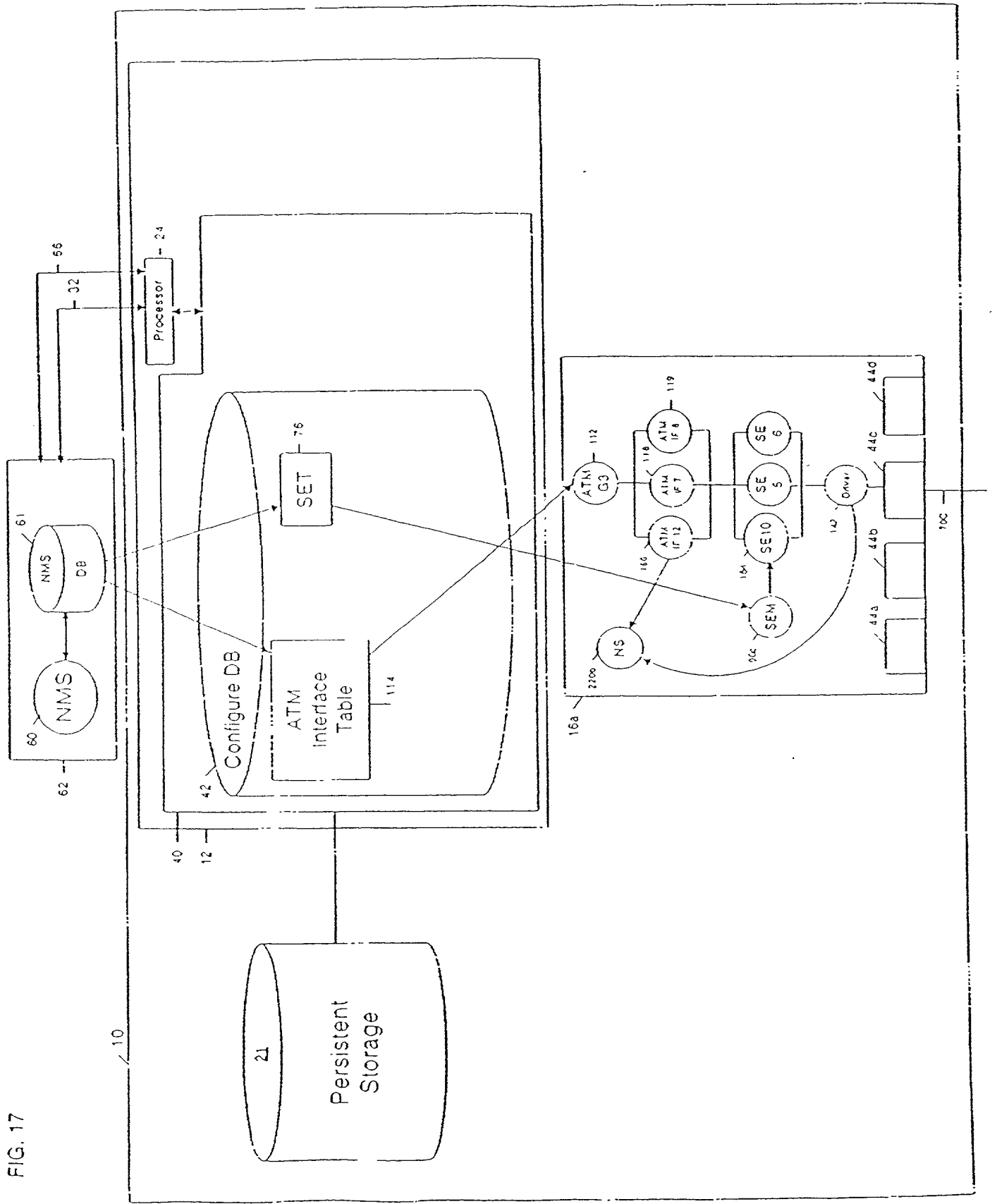
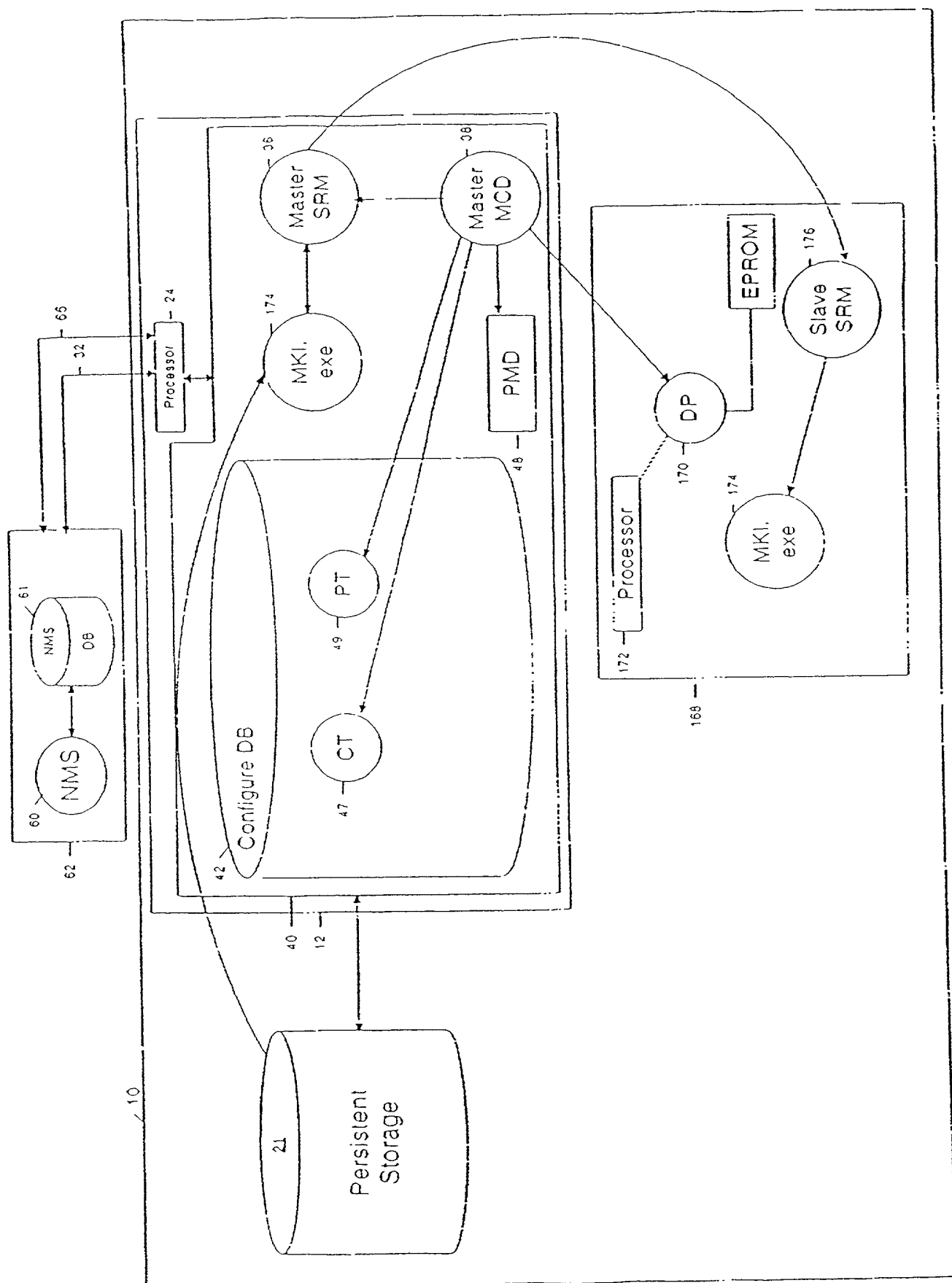




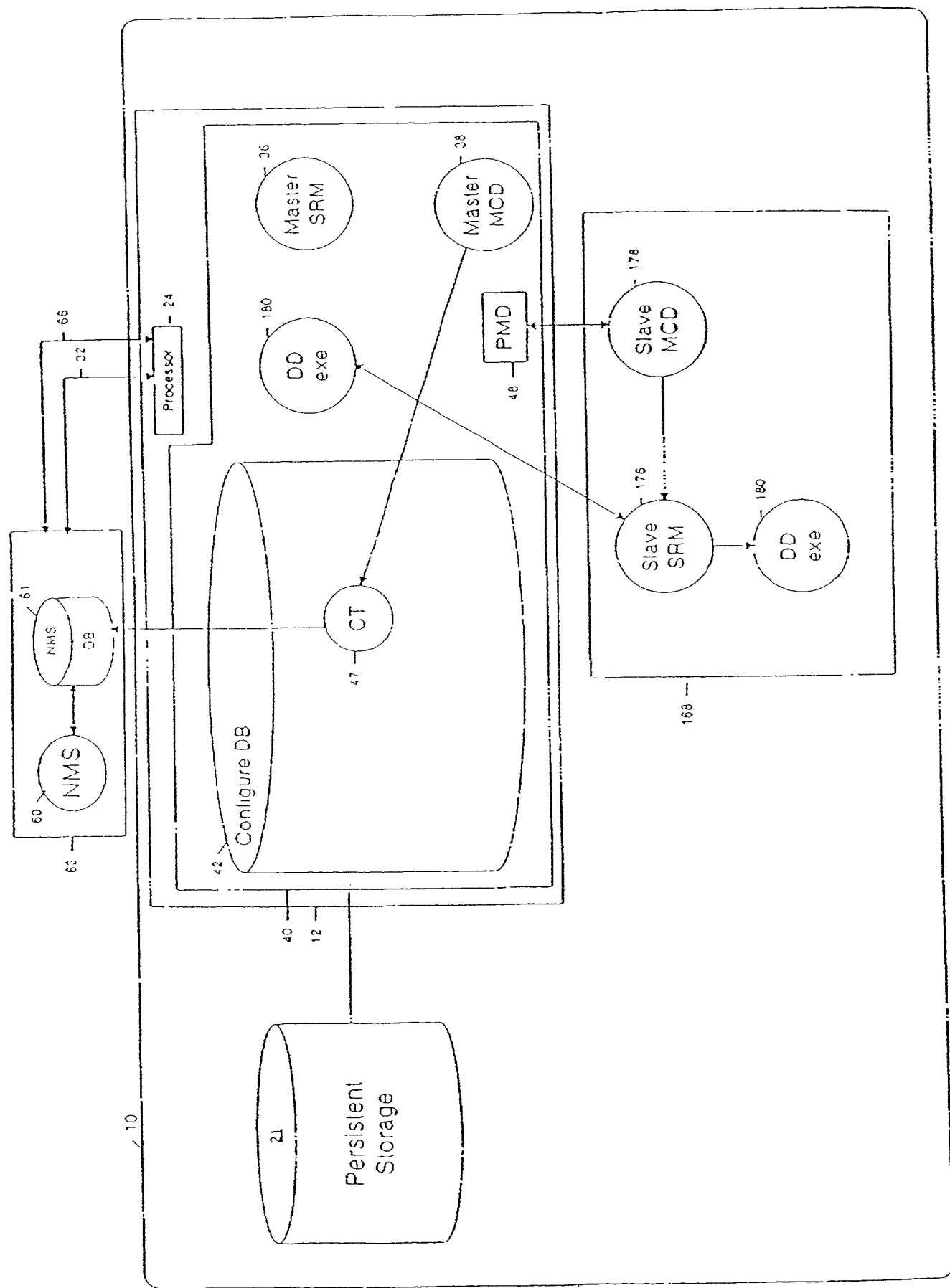


FIG. 17



[illegible]

General Information		Demographics		Clinical History		Physical Examination		Laboratory Studies		Imaging Studies		Treatment		Outcome		
Item	Value	Item	Value	Item	Value	Item	Value	Item	Value	Item	Value	Item	Value	Item	Value	
Age	45	Sex	Male	Chief Complaint	Headache	Location	Right side	Duration	3 days	Severity	7/10	Associated Symptoms	Nausea	Yes	Frequency	3 times
Weight	70 kg	Height	175 cm	Medical History	Hypertension	Medications	Lisinopril	Physical Exam	Normal	Laboratory	Normal	Imaging	Normal	Treatment	Acetaminophen	Outcome
Blood Pressure	120/80	Heart Rate	72 bpm	Family History	None	Physical Exam	Normal	Laboratory	Normal	Imaging	Normal	Treatment	Acetaminophen	Outcome	Improved	
Blood Sugar	100 mg/dL	Blood Cholesterol	200 mg/dL	Physical Exam	Normal	Laboratory	Normal	Imaging	Normal	Treatment	Acetaminophen	Outcome	Improved	Improved		
Blood Urea Nitrogen	10 mg/dL	Blood Creatinine	1.0 mg/dL	Physical Exam	Normal	Laboratory	Normal	Imaging	Normal	Treatment	Acetaminophen	Outcome	Improved	Improved		
Blood Glucose	100 mg/dL	Blood Hemoglobin	15 g/dL	Physical Exam	Normal	Laboratory	Normal	Imaging	Normal	Treatment	Acetaminophen	Outcome	Improved	Improved		
Blood Hematocrit	45%	Blood Hemoglobin	15 g/dL	Physical Exam	Normal	Laboratory	Normal	Imaging	Normal	Treatment	Acetaminophen	Outcome	Improved	Improved		
Blood Hemoglobin	15 g/dL	Blood Hematocrit	45%	Physical Exam	Normal	Laboratory	Normal	Imaging	Normal	Treatment	Acetaminophen	Outcome	Improved	Improved		
Blood Hematocrit	45%	Blood Hemoglobin	15 g/dL	Physical Exam	Normal	Laboratory	Normal	Imaging	Normal	Treatment	Acetaminophen	Outcome	Improved	Improved		
Blood Hemoglobin	15 g/dL	Blood Hematocrit	45%	Physical Exam	Normal	Laboratory	Normal	Imaging	Normal	Treatment	Acetaminophen	Outcome	Improved	Improved		
Blood Hematocrit	45%	Blood Hemoglobin	15 g/dL	Physical Exam	Normal	Laboratory	Normal	Imaging	Normal	Treatment	Acetaminophen	Outcome	Improved	Improved		
Blood Hemoglobin	15 g/dL	Blood Hematocrit	45%	Physical Exam	Normal	Laboratory	Normal	Imaging	Normal	Treatment	Acetaminophen	Outcome	Improved	Improved		
Blood Hematocrit	45%	Blood Hemoglobin	15 g/dL	Physical Exam	Normal	Laboratory	Normal	Imaging	Normal	Treatment	Acetaminophen	Outcome	Improved	Improved		
Blood Hemoglobin	15 g/dL	Blood Hematocrit	45%	Physical Exam	Normal	Laboratory	Normal	Imaging	Normal	Treatment	Acetaminophen	Outcome	Improved	Improved		
Blood Hematocrit	45%	Blood Hemoglobin	15 g/dL	Physical Exam	Normal	Laboratory	Normal	Imaging	Normal	Treatment	Acetaminophen	Outcome	Improved	Improved		
Blood Hemoglobin	15 g/dL	Blood Hematocrit	45%	Physical Exam	Normal	Laboratory	Normal	Imaging	Normal	Treatment	Acetaminophen	Outcome	Improved	Improved		
Blood Hematocrit	45%	Blood Hemoglobin	15 g/dL	Physical Exam	Normal	Laboratory	Normal	Imaging	Normal	Treatment	Acetaminophen	Outcome	Improved	Improved		
Blood Hemoglobin	15 g/dL	Blood Hematocrit	45%	Physical Exam	Normal	Laboratory	Normal	Imaging	Normal	Treatment	Acetaminophen	Outcome	Improved	Improved		
Blood Hematocrit	45%	Blood Hemoglobin	15 g/dL	Physical Exam	Normal	Laboratory	Normal	Imaging	Normal	Treatment	Acetaminophen	Outcome	Improved	Improved		
Blood Hemoglobin	15 g/dL	Blood Hematocrit	45%	Physical Exam	Normal	Laboratory	Normal	Imaging	Normal	Treatment	Acetaminophen	Outcome	Improved	Improved		
Blood Hematocrit	45%	Blood Hemoglobin	15 g/dL	Physical Exam	Normal	Laboratory	Normal	Imaging	Normal	Treatment	Acetaminophen	Outcome	Improved	Improved		
Blood Hemoglobin	15 g/dL	Blood Hematocrit	45%	Physical Exam	Normal	Laboratory	Normal	Imaging	Normal	Treatment	Acetaminophen	Outcome	Improved	Improved		
Blood Hematocrit	45%	Blood Hemoglobin	15 g/dL	Physical Exam	Normal	Laboratory	Normal	Imaging	Normal	Treatment	Acetaminophen	Outcome	Improved	Improved		
Blood Hemoglobin	15 g/dL	Blood Hematocrit	45%	Physical Exam	Normal	Laboratory	Normal	Imaging	Normal	Treatment	Acetaminophen	Outcome	Improved	Improved		
Blood Hematocrit	45%	Blood Hemoglobin	15 g/dL	Physical Exam	Normal	Laboratory	Normal	Imaging	Normal	Treatment	Acetaminophen	Outcome	Improved	Improved		
Blood Hemoglobin	15 g/dL	Blood Hematocrit	45%	Physical Exam	Normal	Laboratory	Normal	Imaging	Normal	Treatment	Acetaminophen	Outcome	Improved	Improved		
Blood Hematocrit	45%	Blood Hemoglobin	15 g/dL	Physical Exam	Normal	Laboratory	Normal	Imaging	Normal	Treatment	Acetaminophen	Outcome	Improved	Improved		
Blood Hemoglobin	15 g/dL	Blood Hematocrit	45%	Physical Exam	Normal	Laboratory	Normal	Imaging	Normal	Treatment	Acetaminophen	Outcome	Improved	Improved		
Blood Hematocrit	45%	Blood Hemoglobin	15 g/dL	Physical Exam	Normal	Laboratory	Normal	Imaging	Normal	Treatment	Acetaminophen	Outcome	Improved	Improved		
Blood Hemoglobin	15 g/dL	Blood Hematocrit	45%	Physical Exam	Normal	Laboratory										



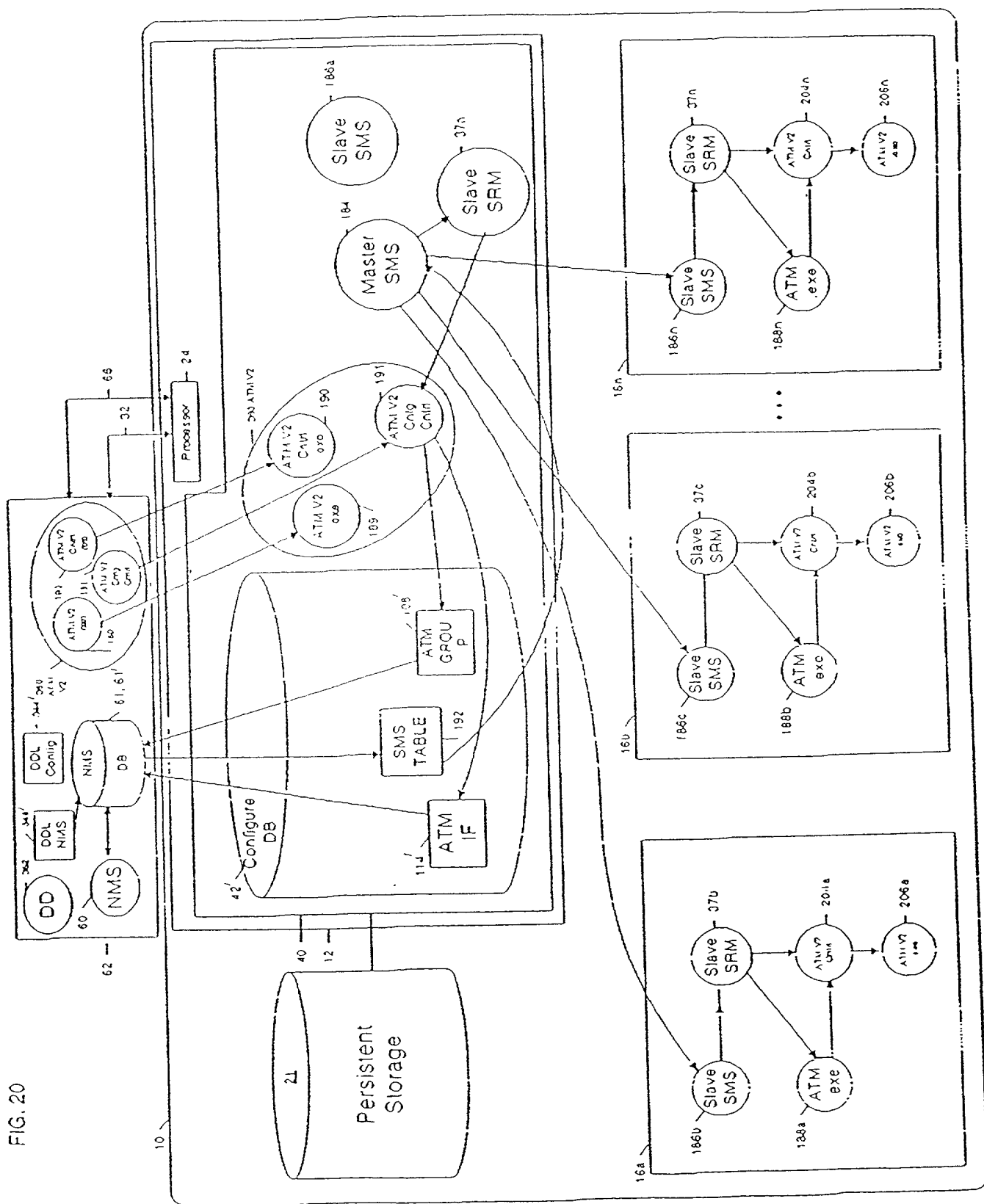
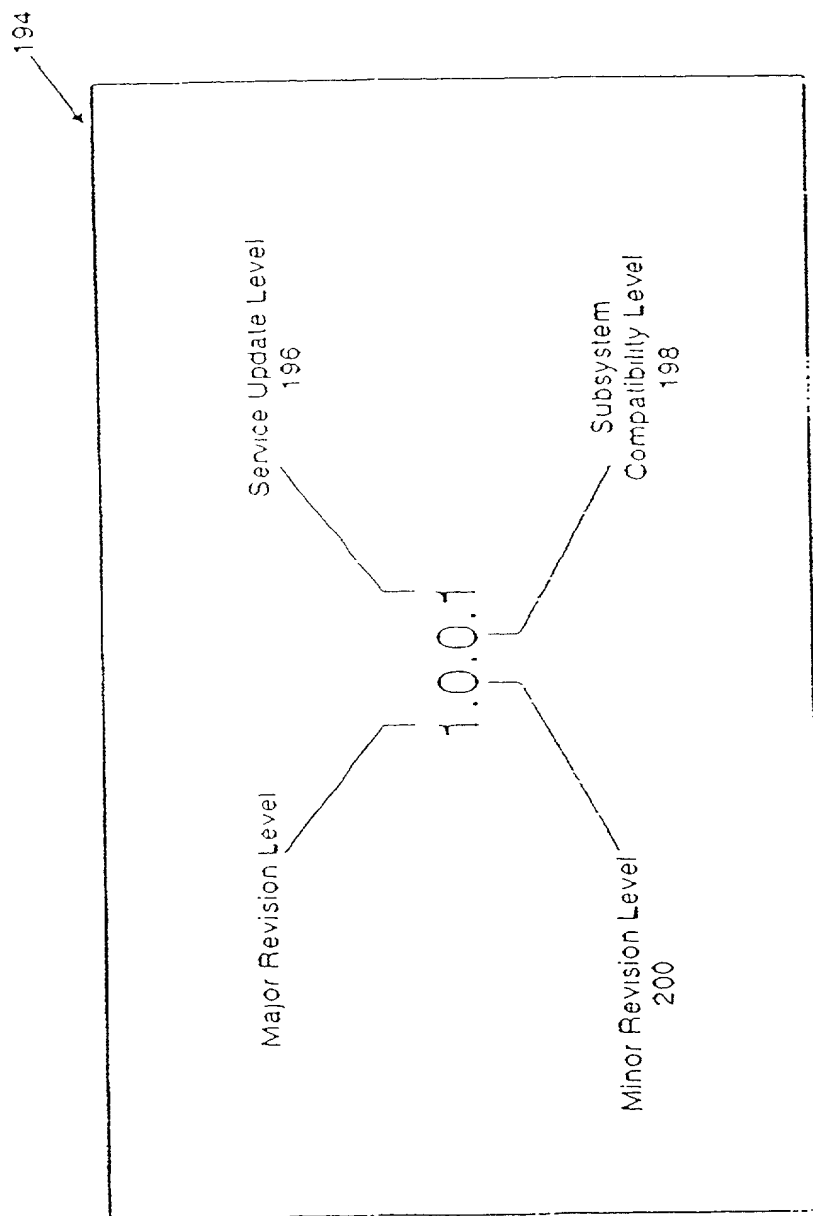


FIG. 21





F/G. 22

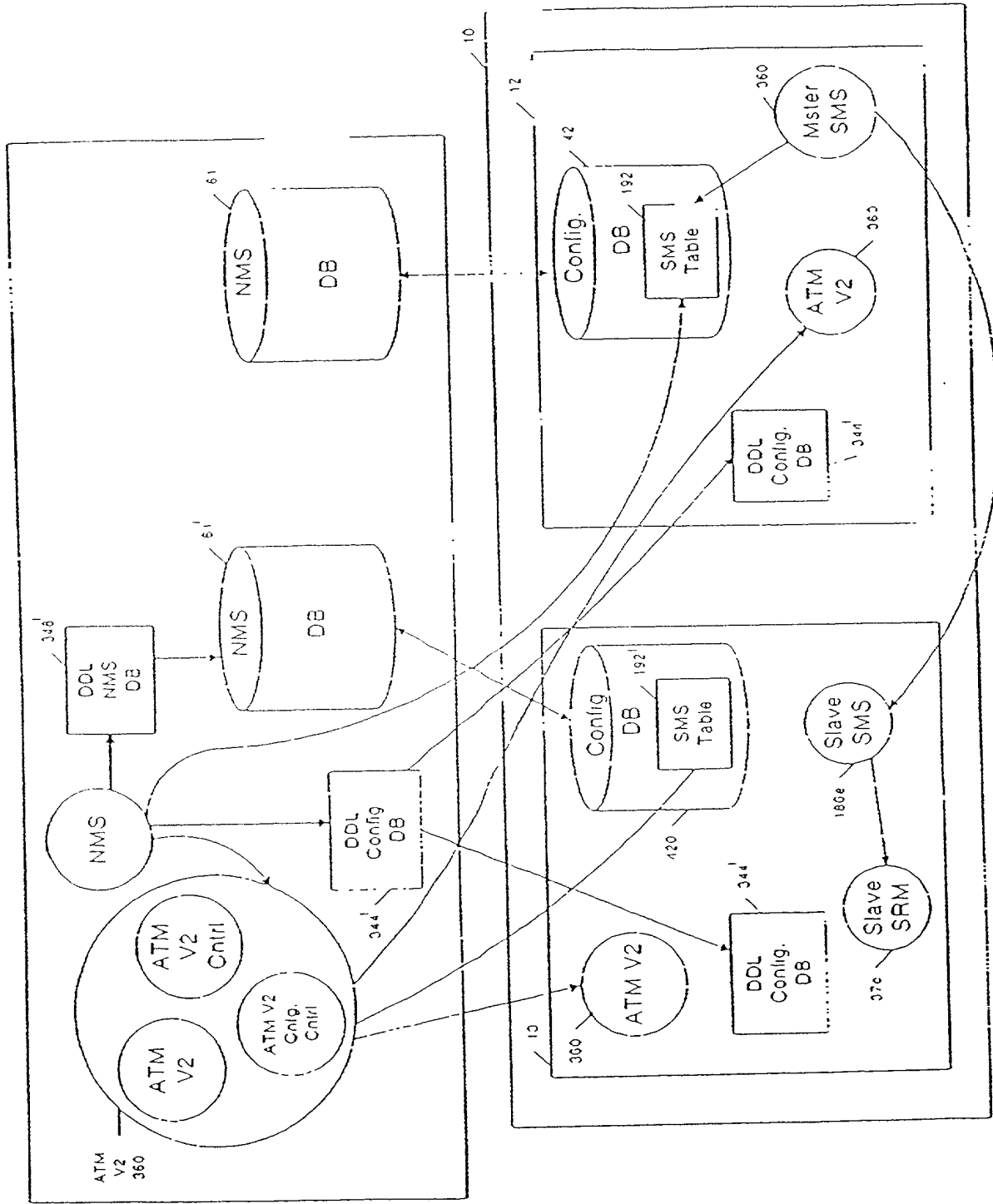




FIG. 24

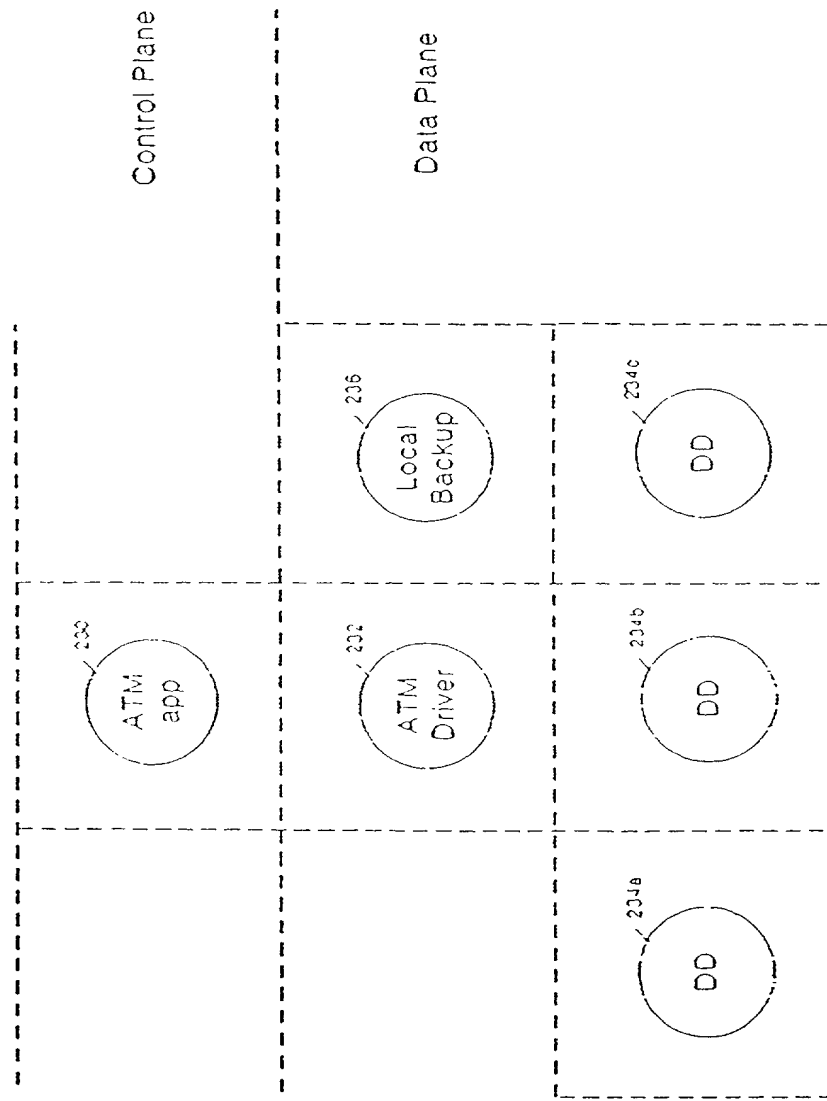


FIG. 25

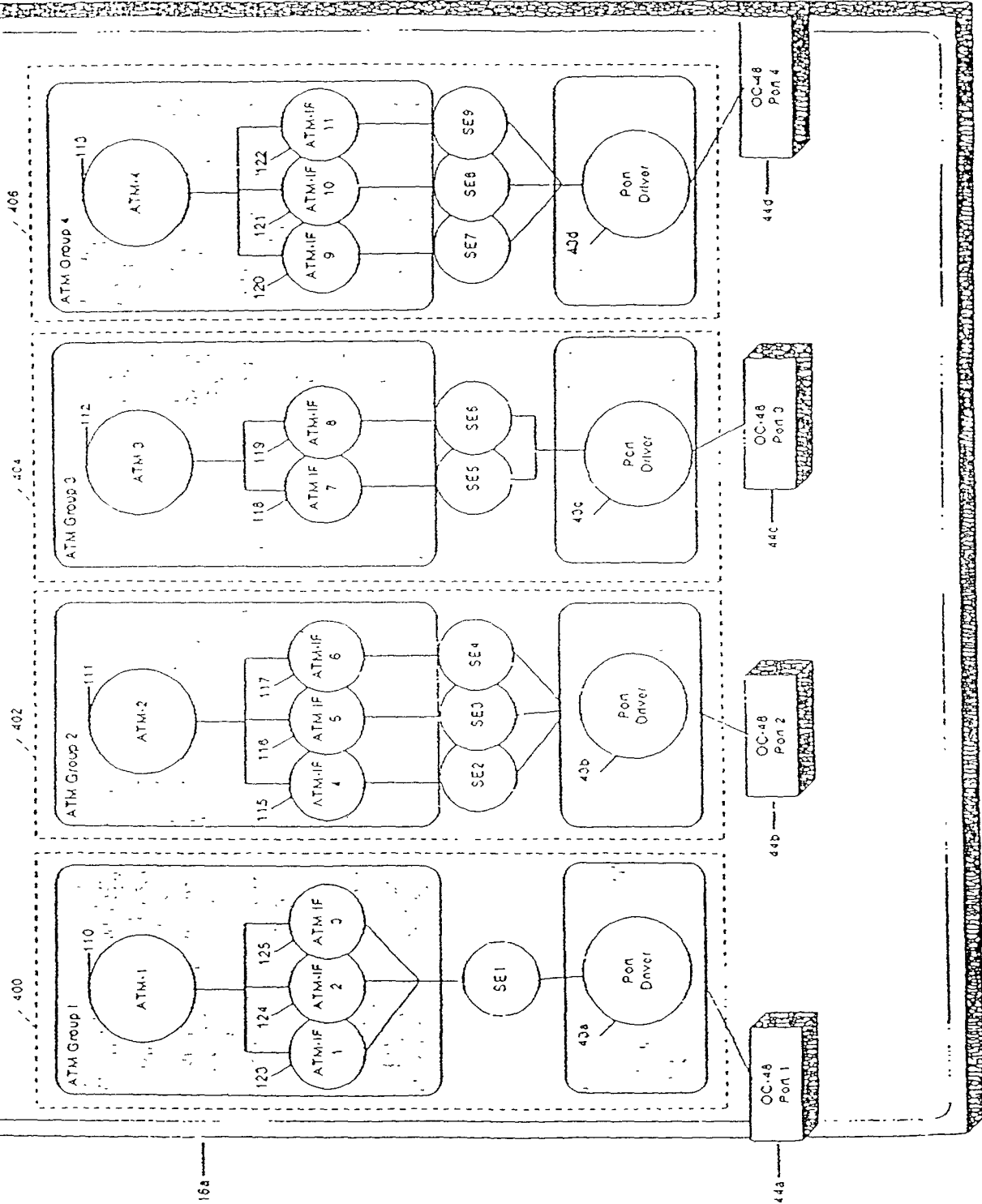


FIG. 26

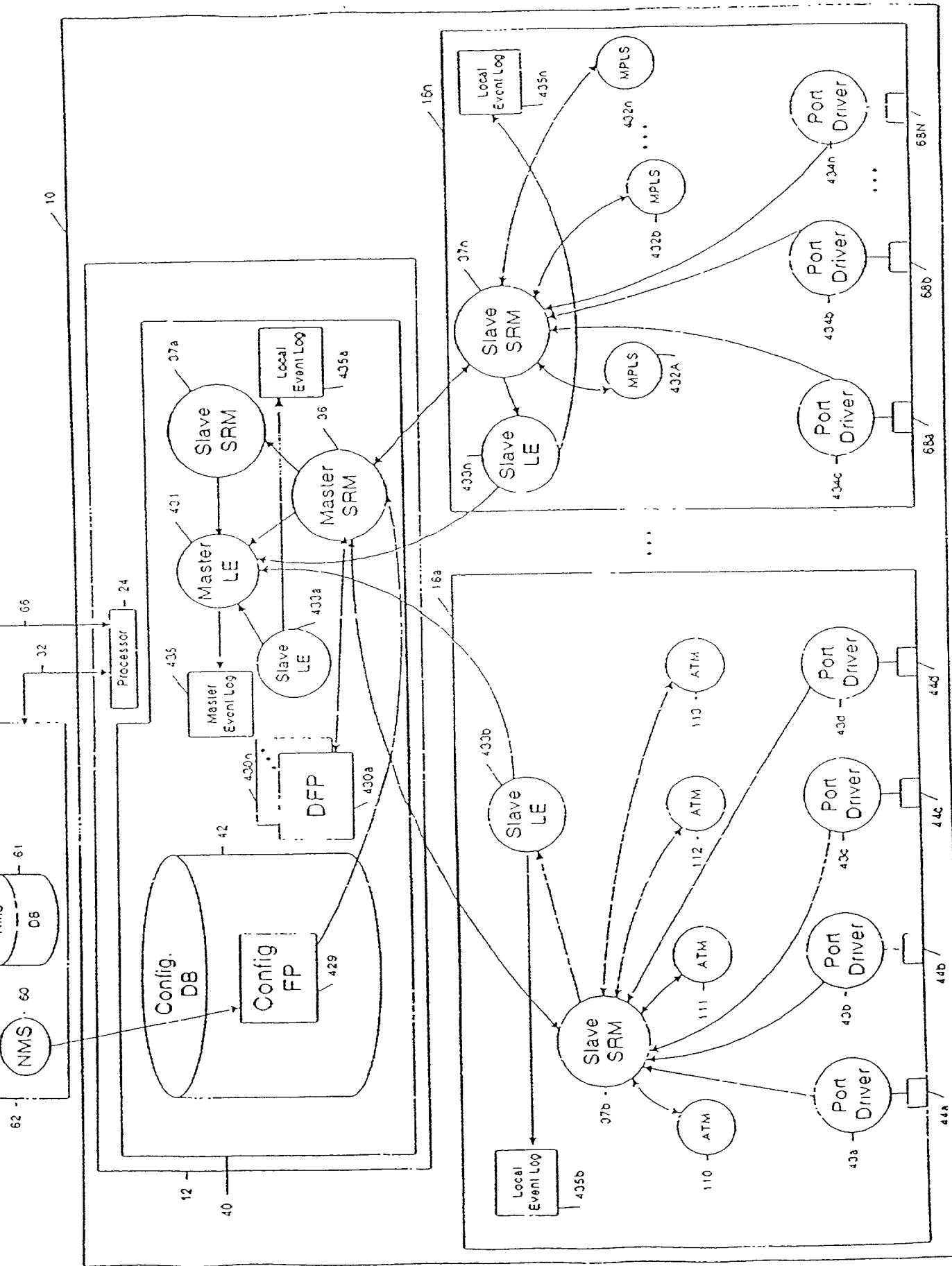


FIG. 27

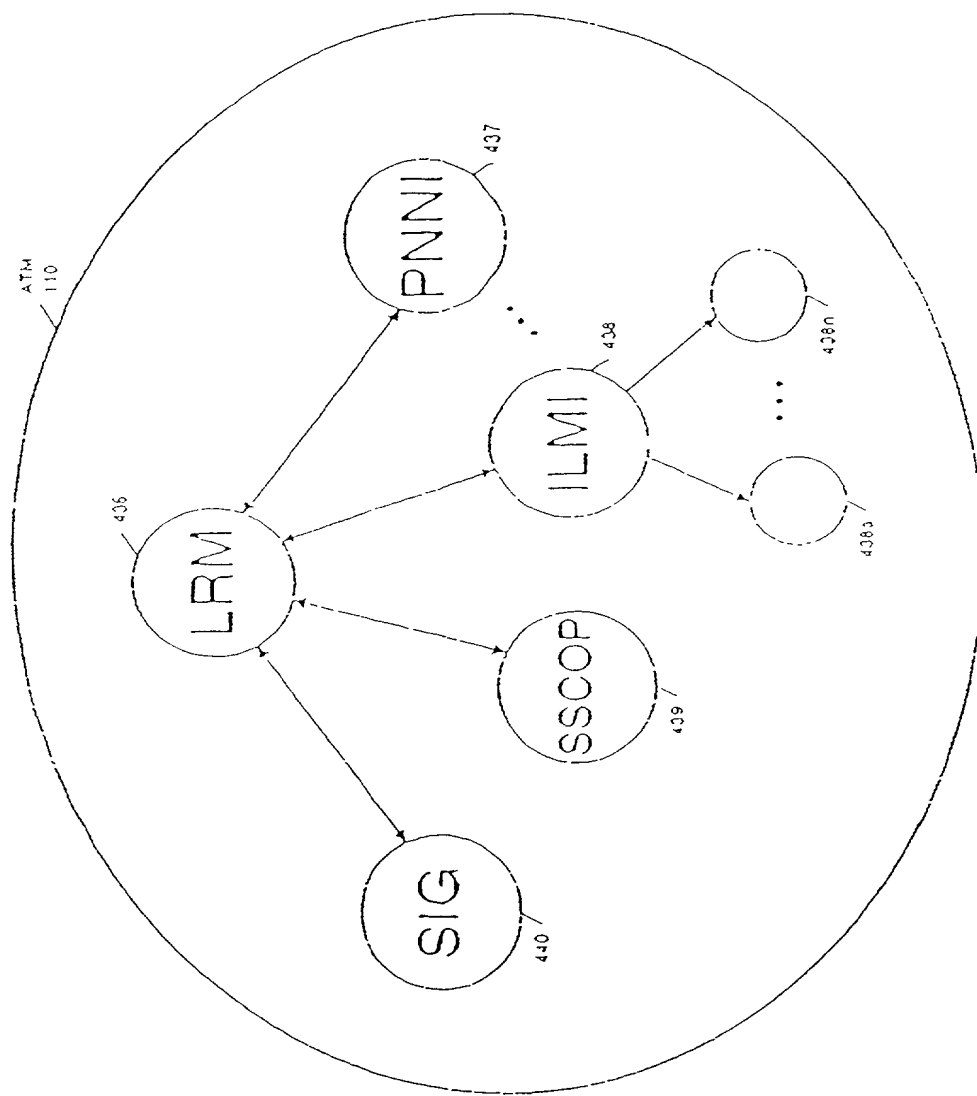


FIG. 29

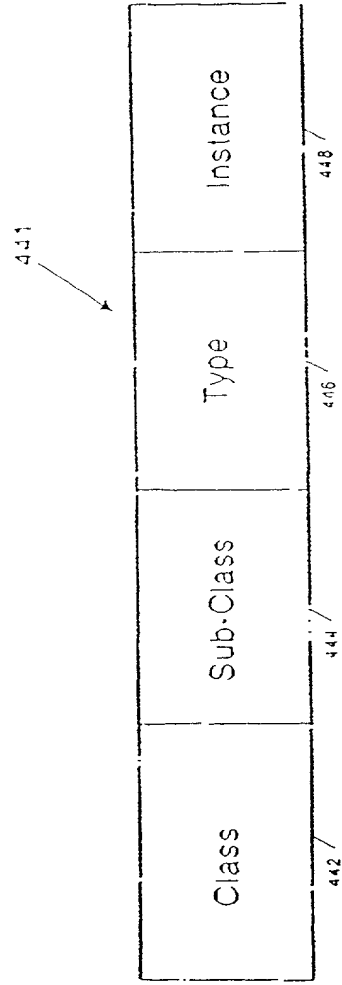
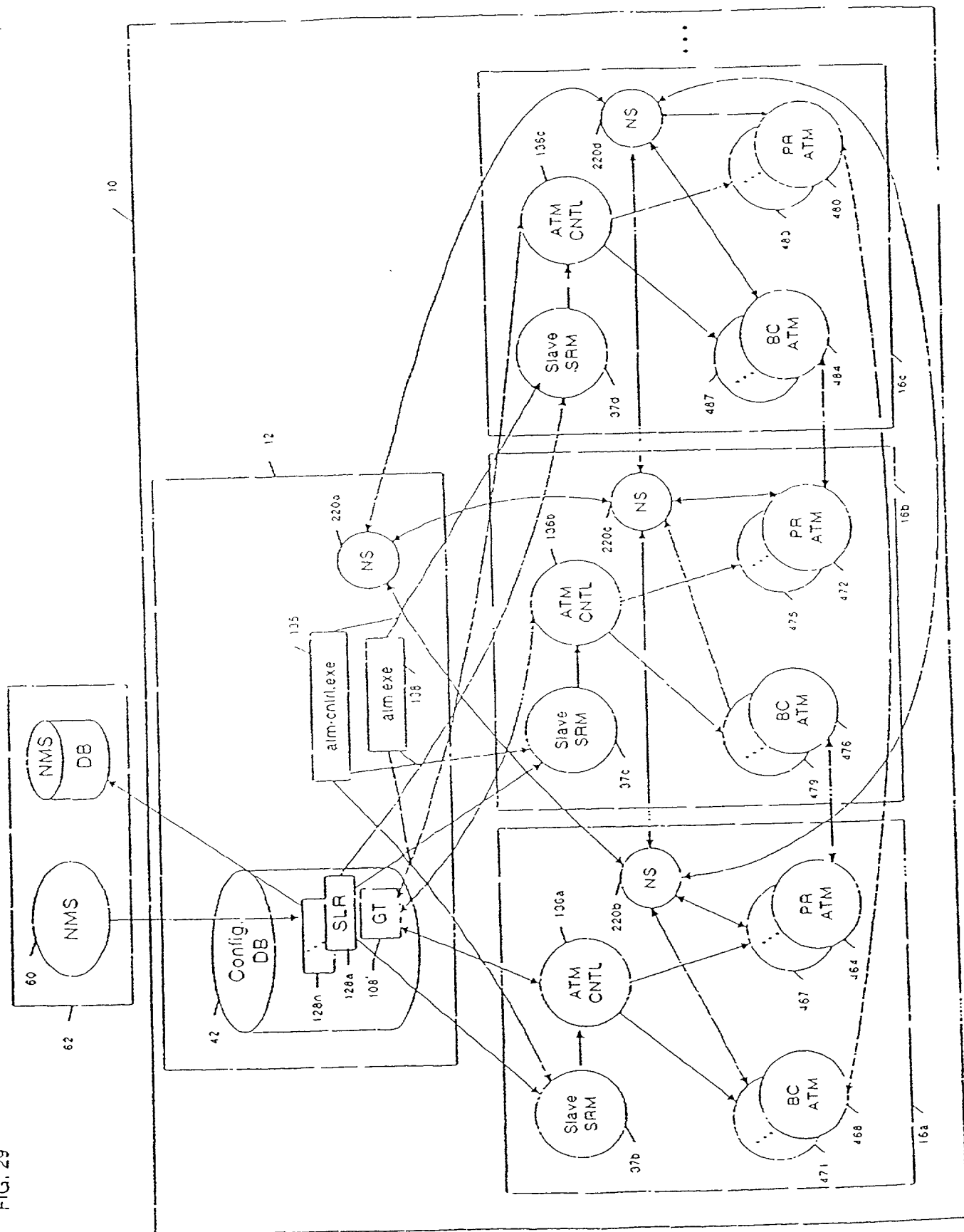


FIG. 29





[illegible]

Group Table 108'

	Group #	Primary Card LID	Backup Card LID	...
450	1	30	31	
451	2	30	31	
452	3	30	31	
453	4	30	31	
454	5	31	32	
455	6	31	32	
456	7	31	32	
457	8	31	32	
458	9	32	30	
459	10	32	30	
460	11	32	30	
461	12	32	30	
	⋮	⋮	⋮	⋮

Fig. 31a

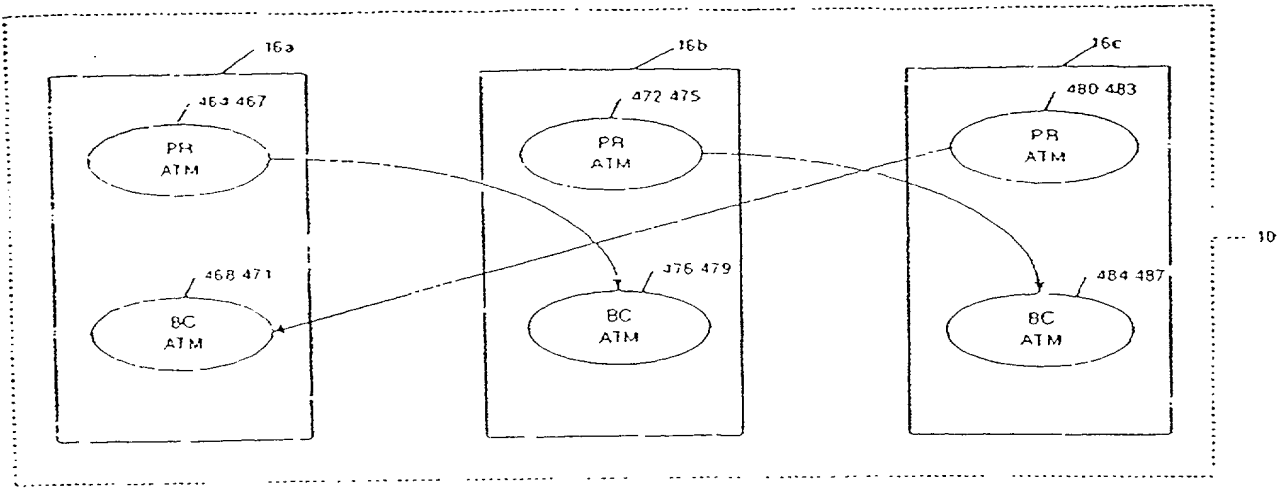


Fig. 31b

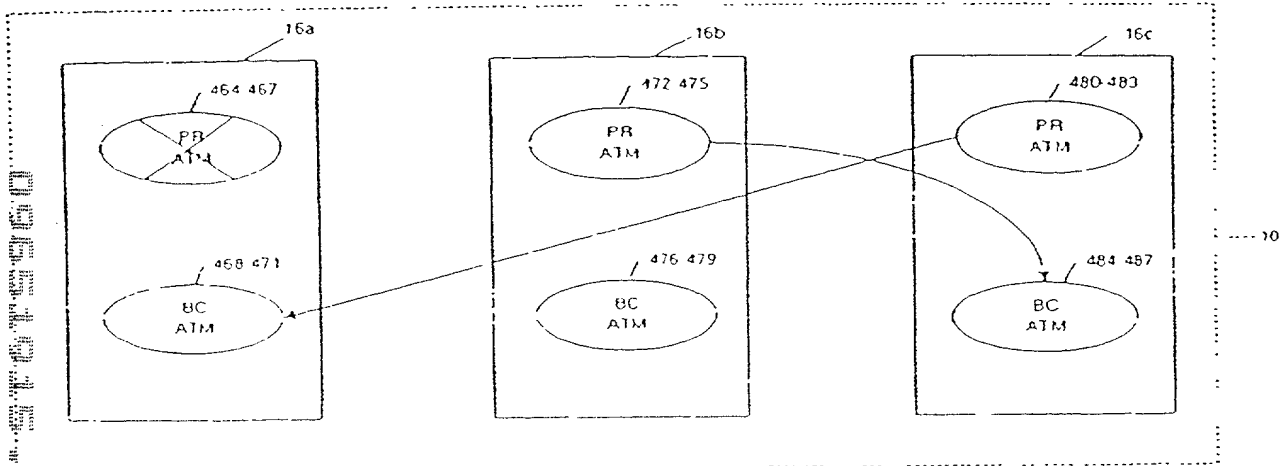


Fig. 31c

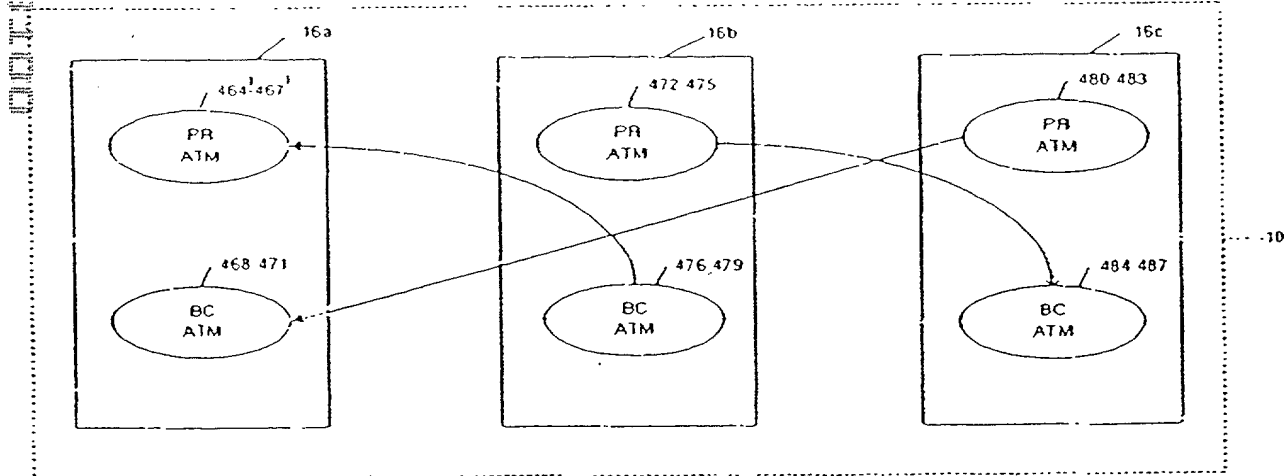


Fig. 32a

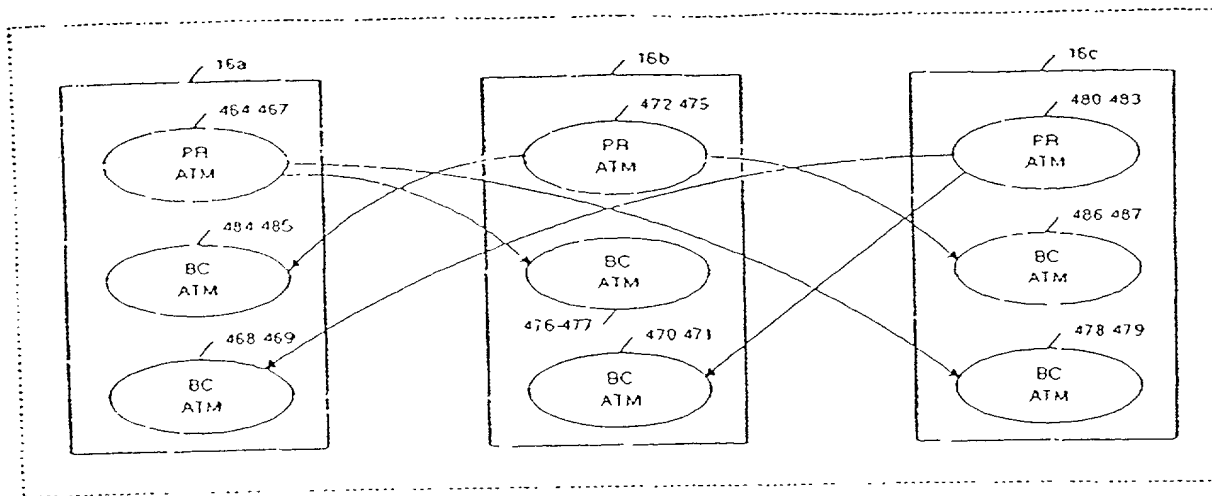


Fig. 32b

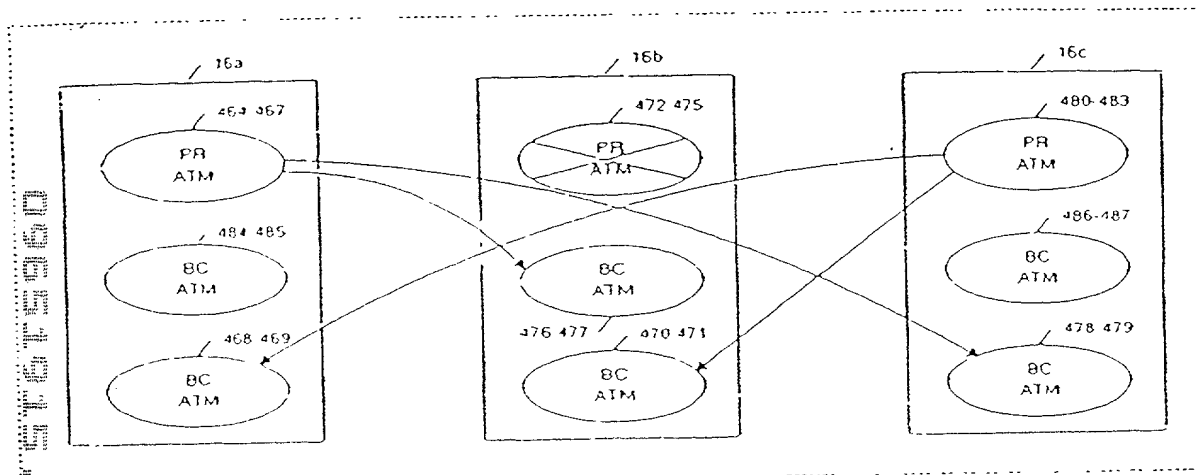


Fig. 32c

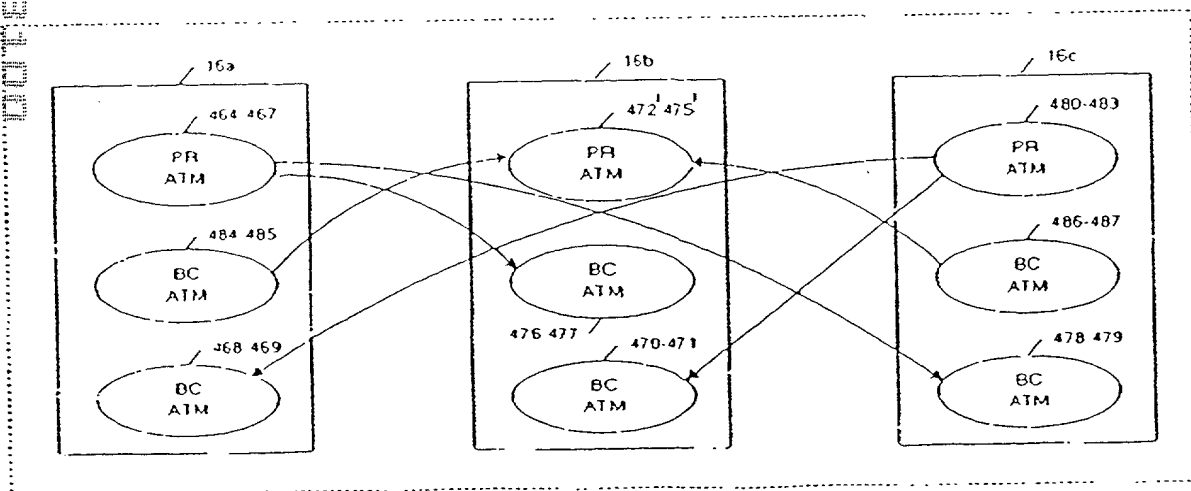


FIG. 33a

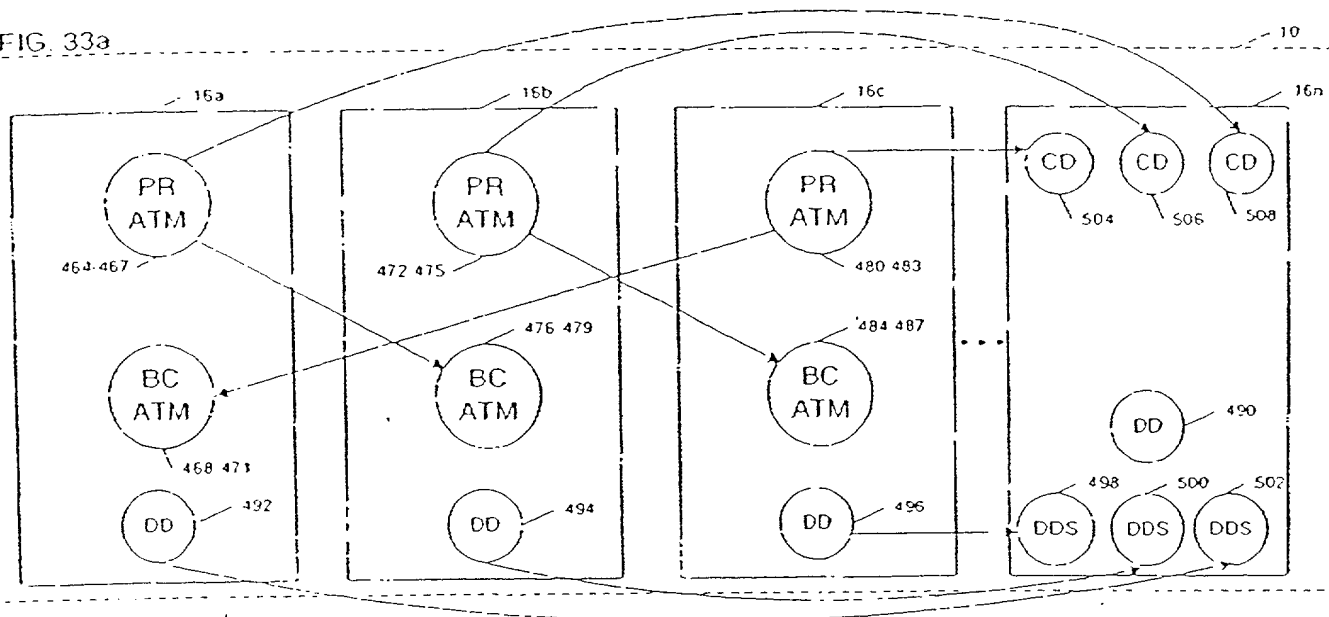


FIG. 33b

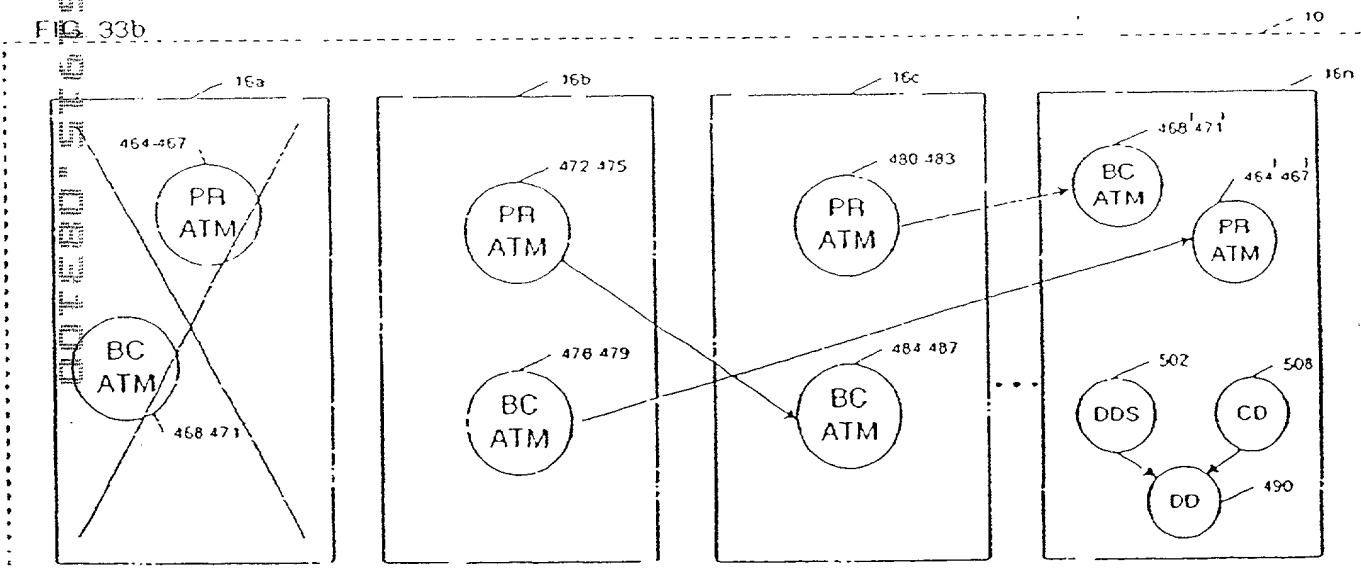


FIG. 33c

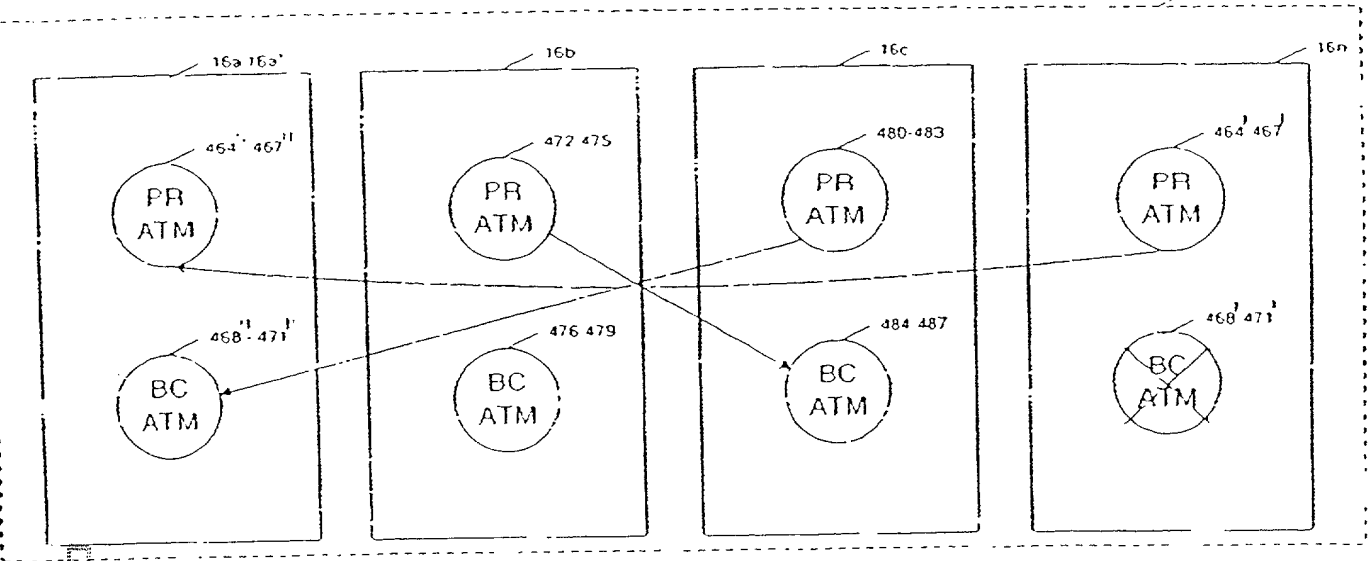


FIG. 33d

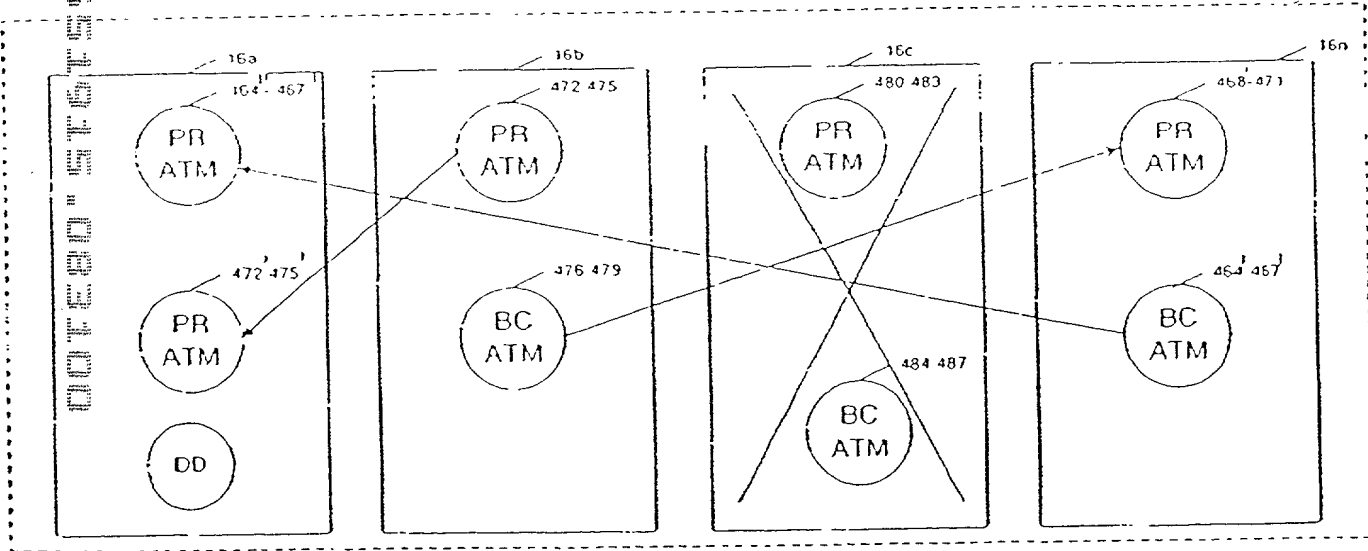


Fig. 34a

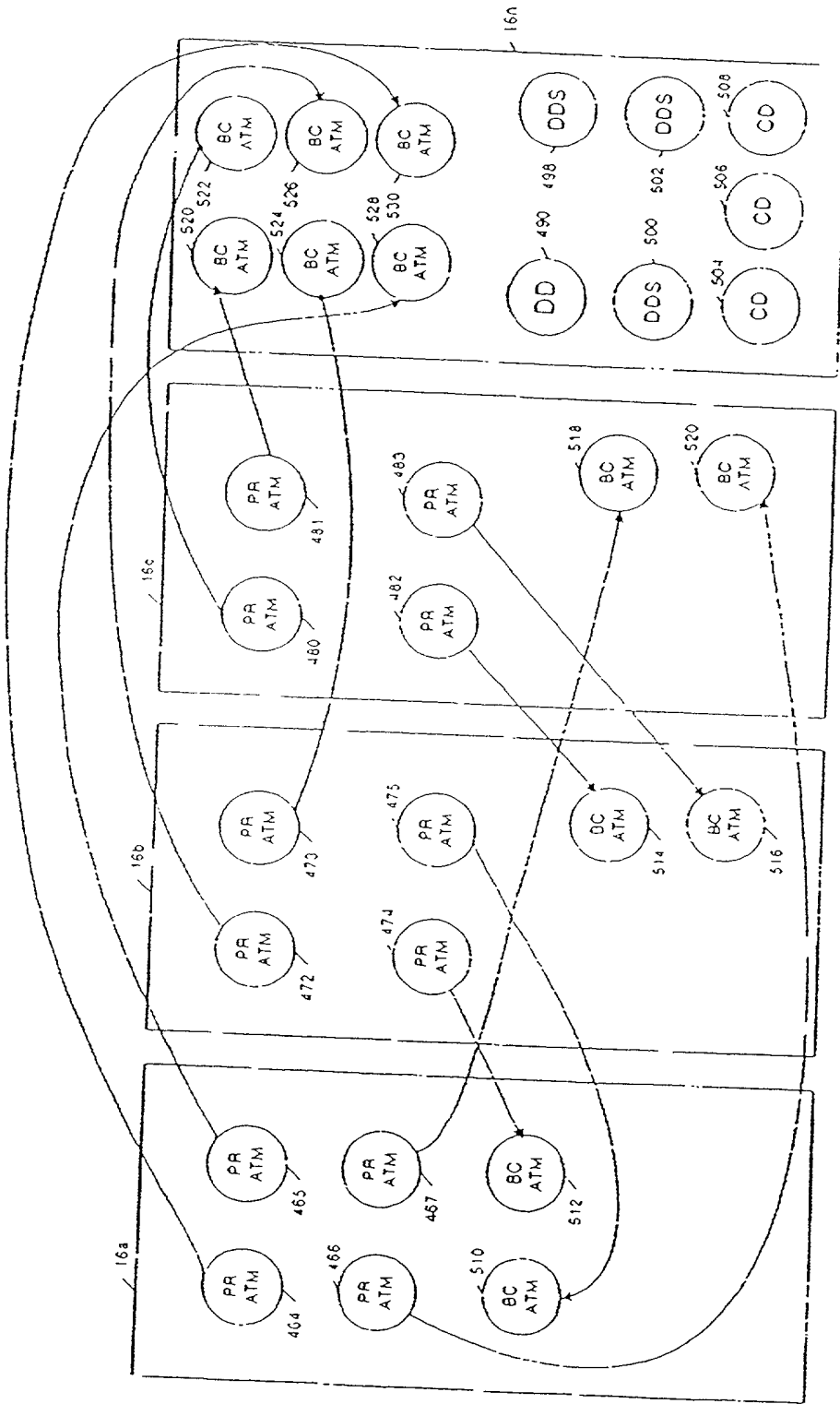


FIG. 34b

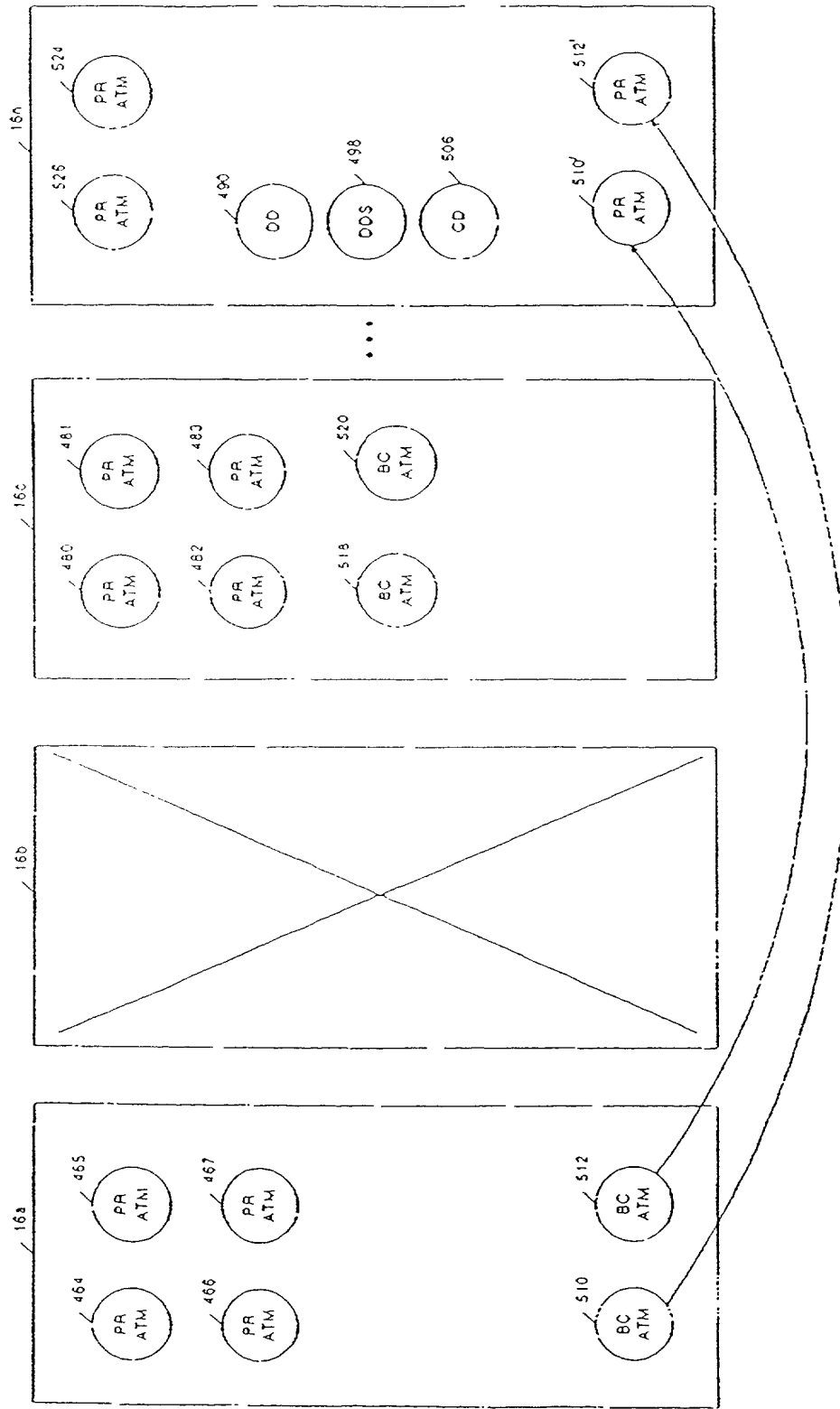


FIG. 35

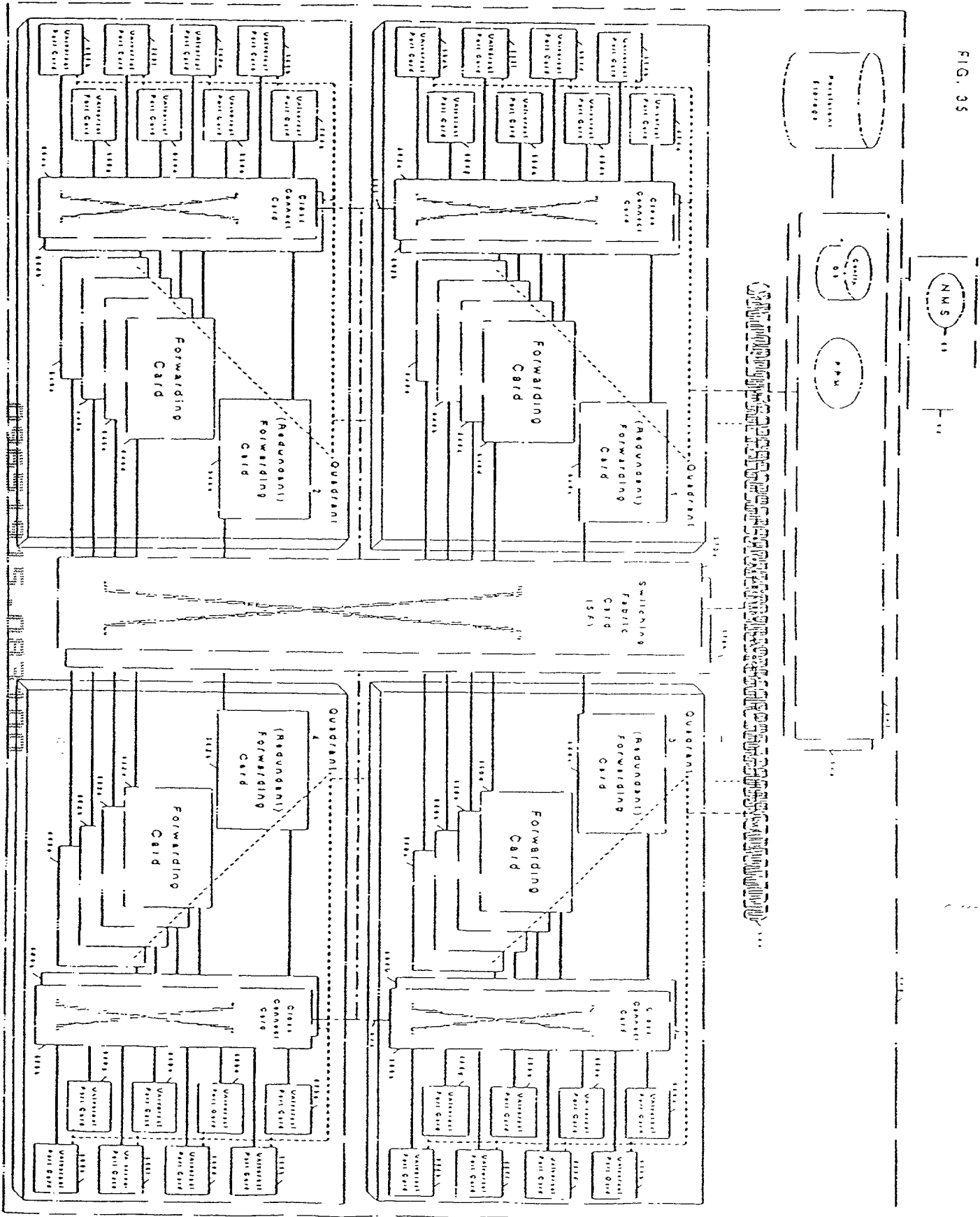
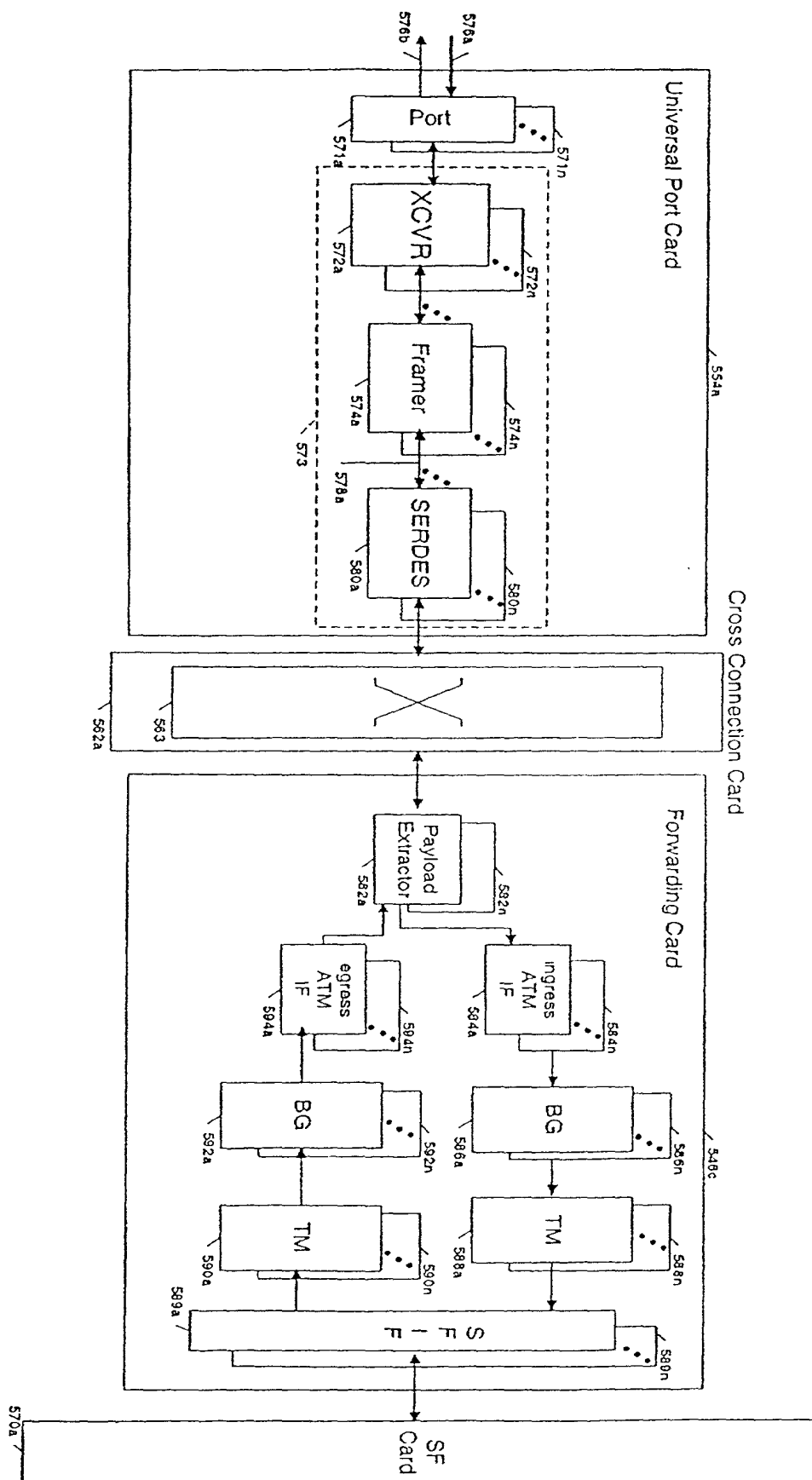




FIG 36



09551913.00000000

FIG. 37

NOTED SET 540

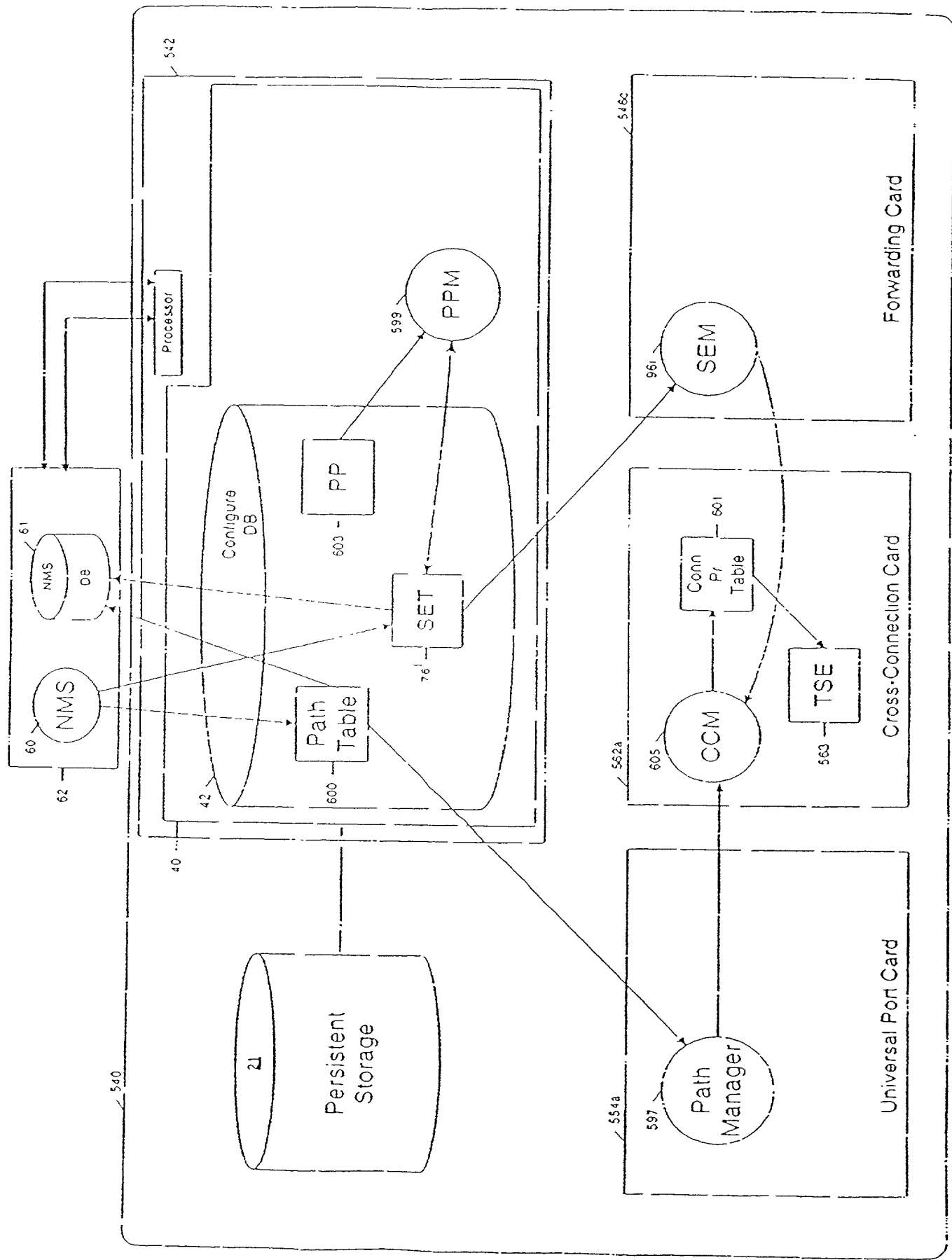


FIG. 38

Path Table 600

602

Path LID	UP Port LID	Time Slot	# of Time Slots	...
1666	1231	4	3	
...	...	...	...	...

FIG. 39

Service End Point Table 76'

SE #	Q #	FC LID	FC Slice	FC Time Slot	Path PID	...
878	1				1666	
...	...	...	...	...	...	...

604

606 608 610

09651915.083100

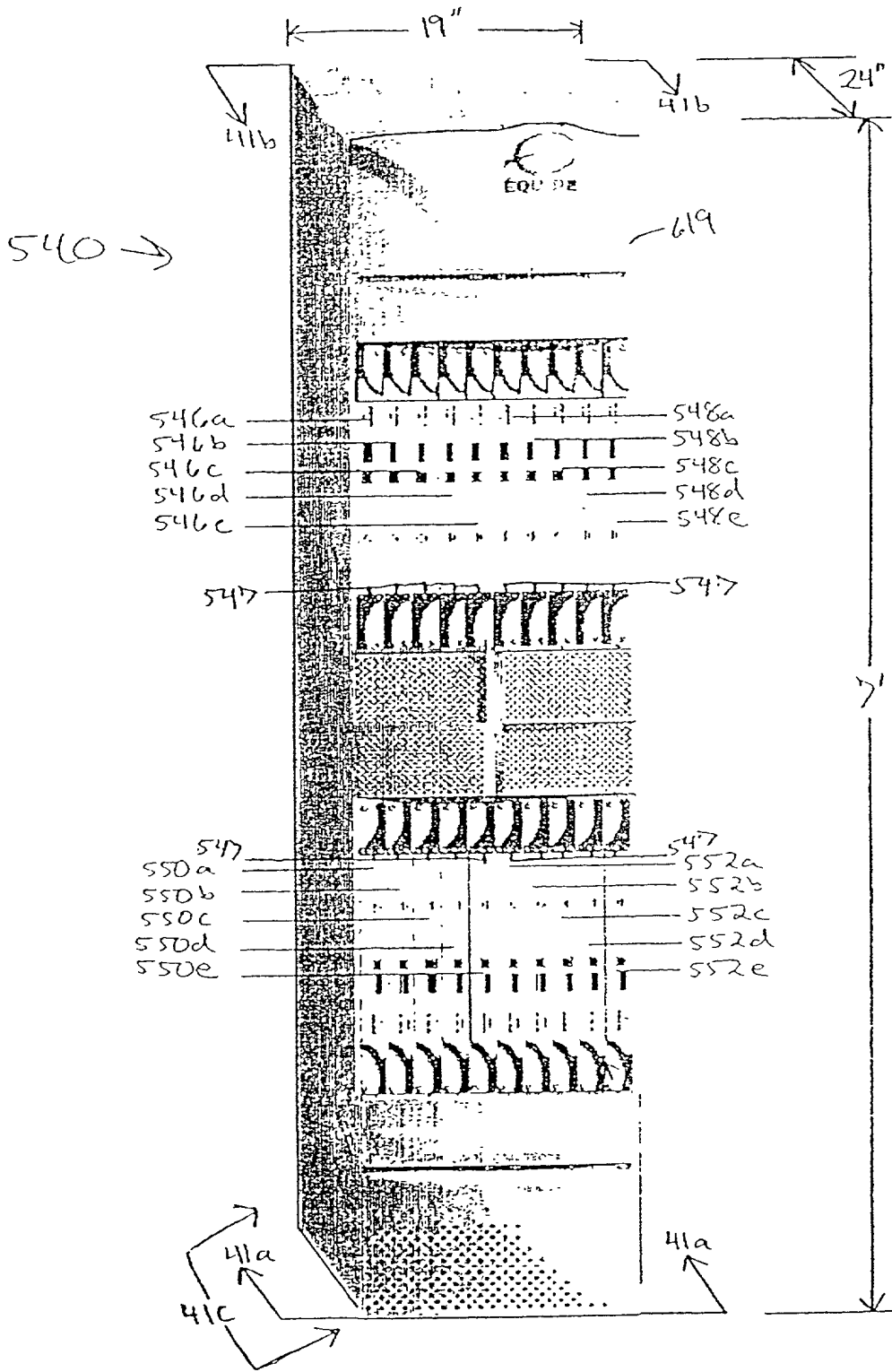
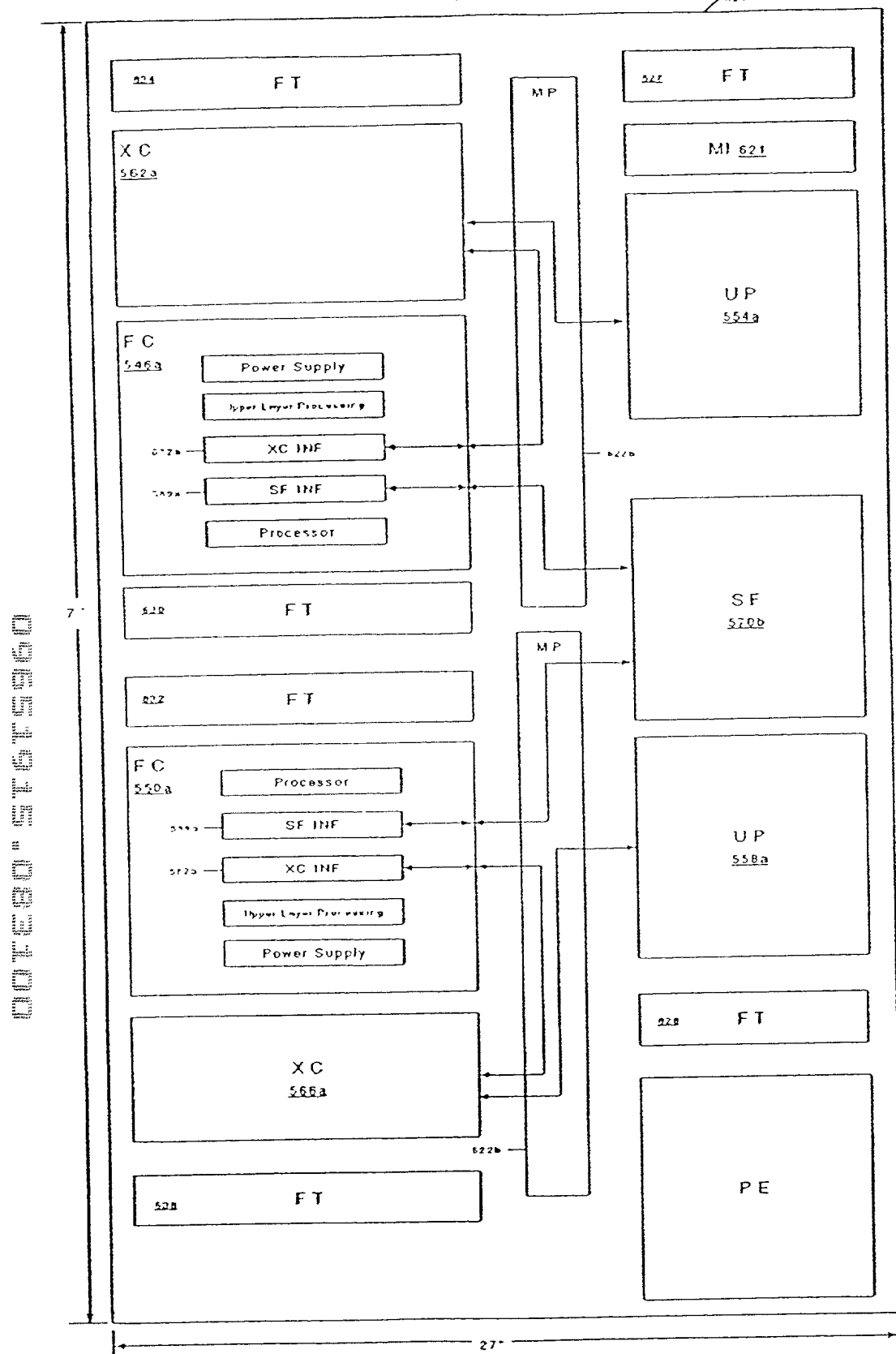


Fig. 40



FIG. 41c  
Side



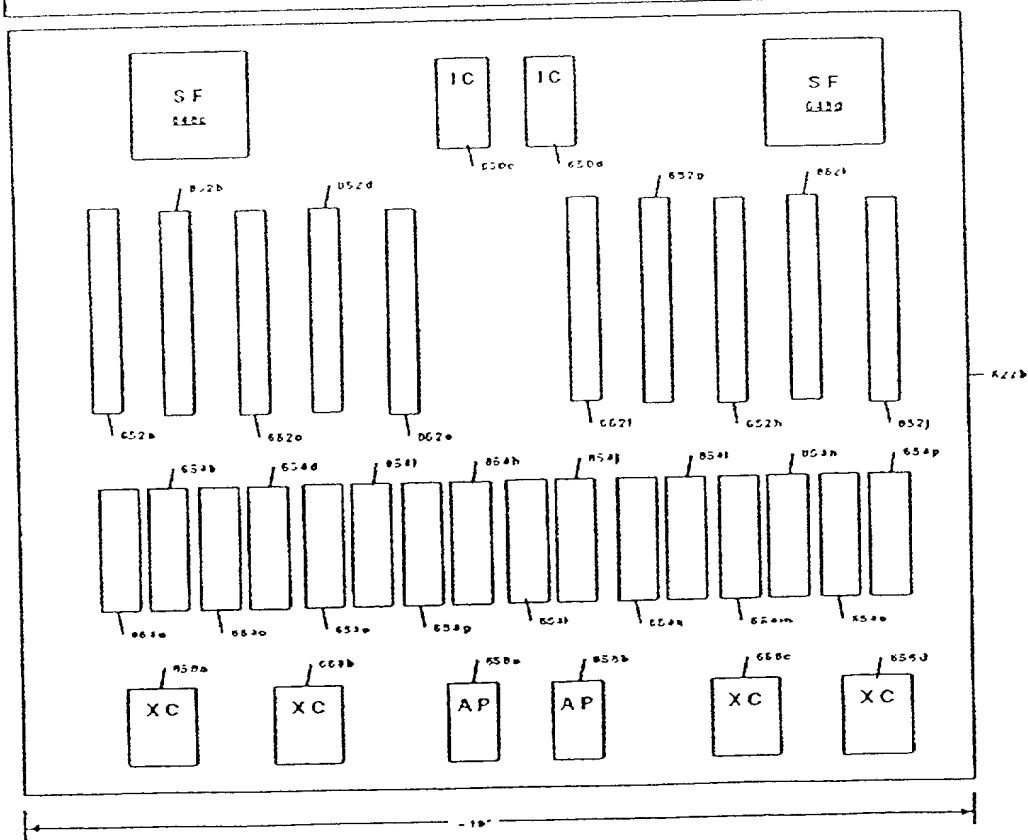
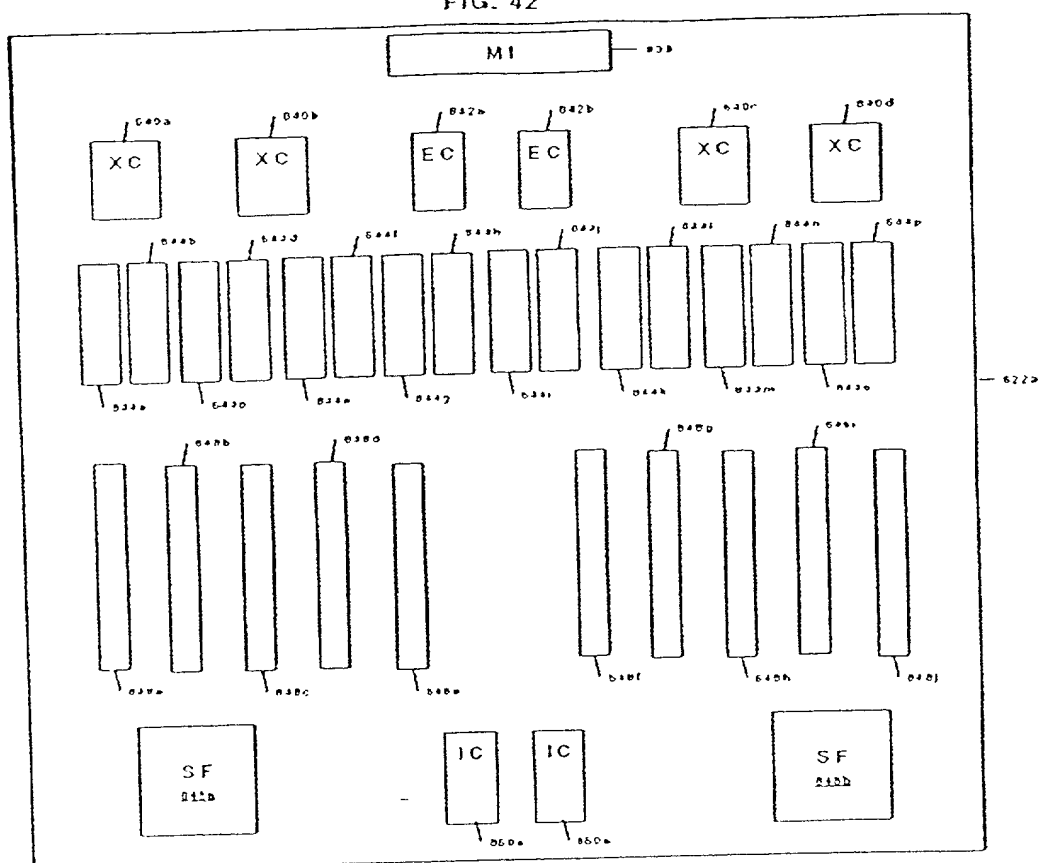
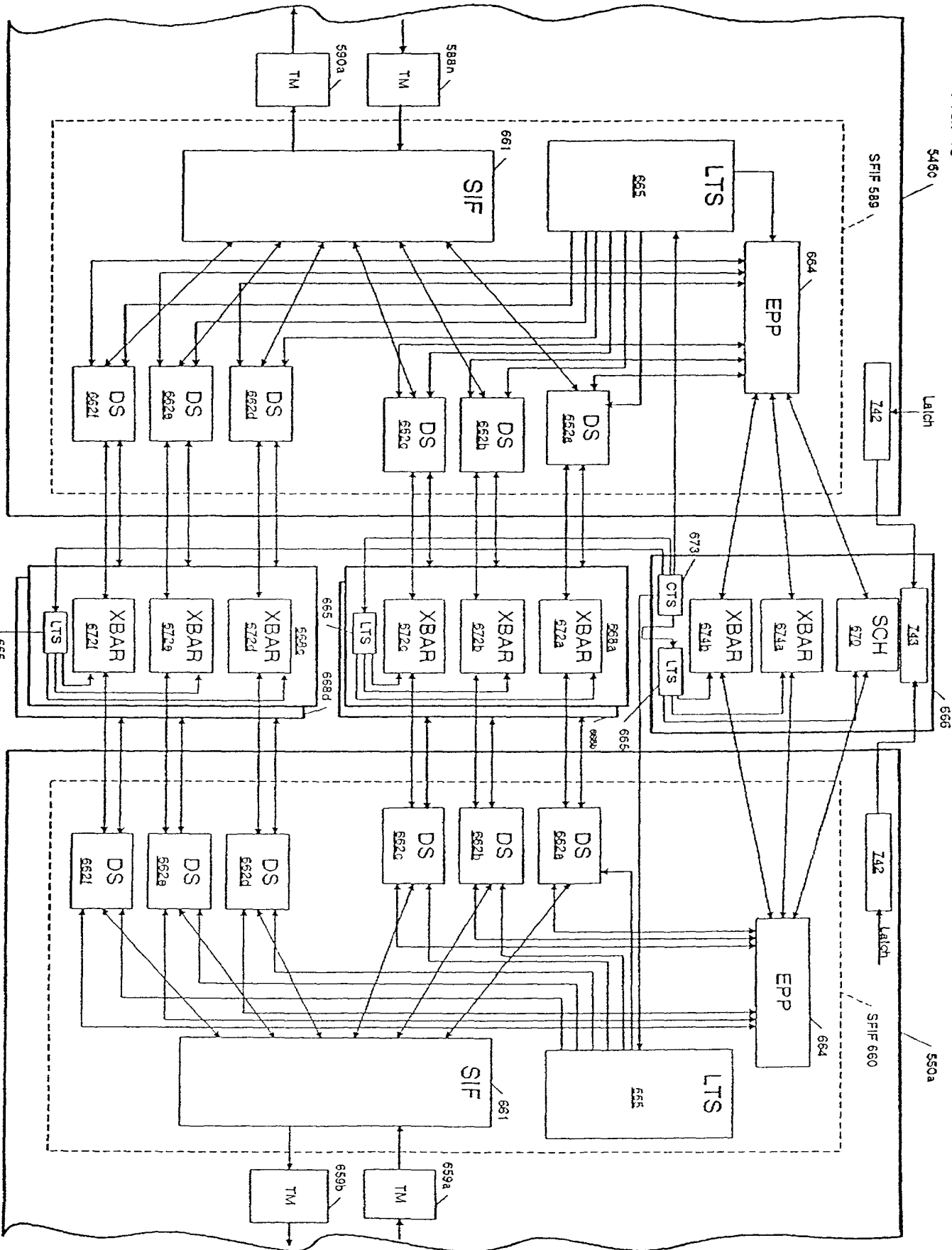




FIG. 43



09:49:49 on 06/04/00

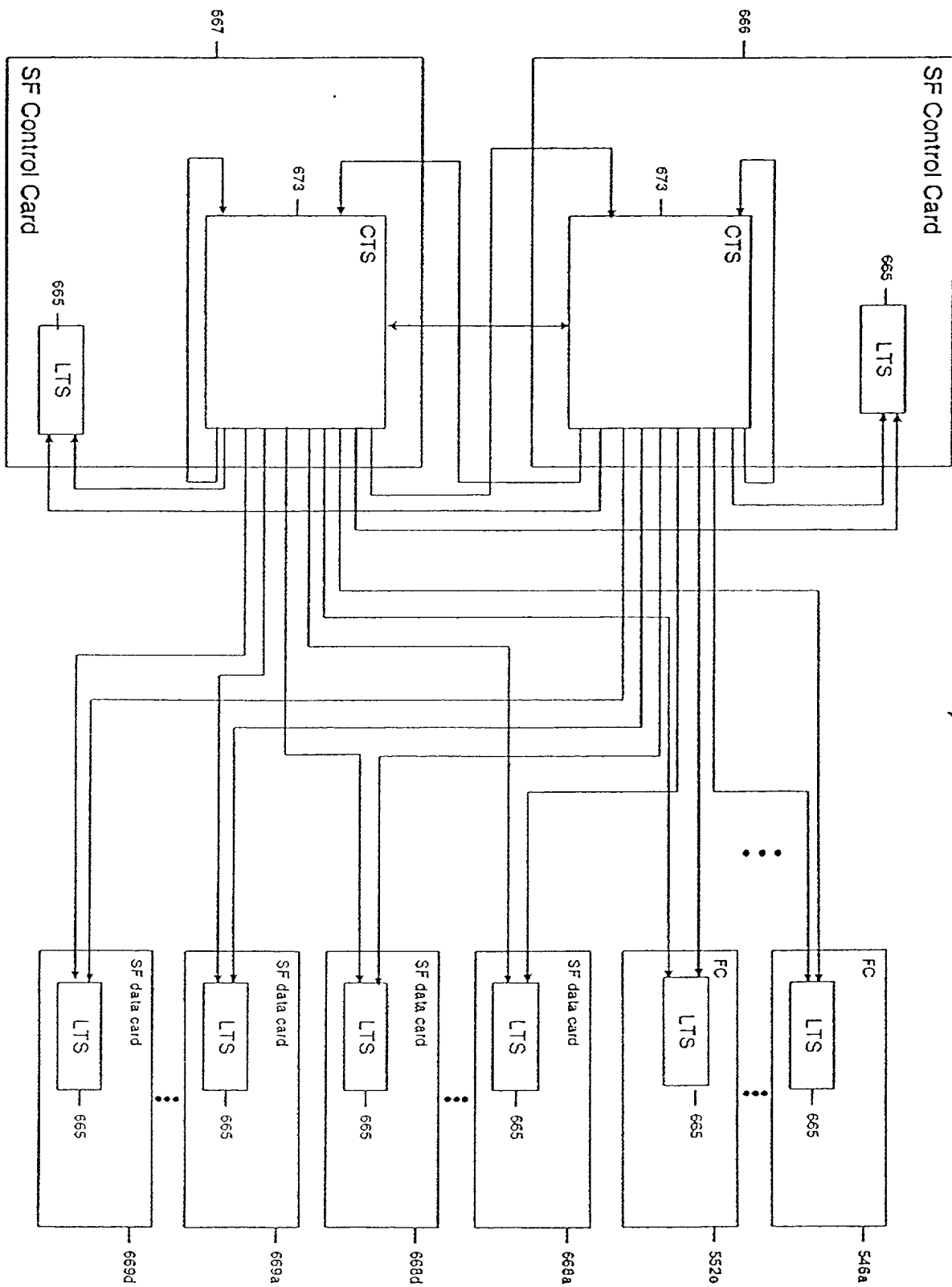
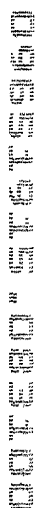


FIG. 44

09631913 003100

673



Q



FIG. 46



0968 25 0870

Parameter	Unit	Value	Standard Error	t-value	p-value
Intercept		1.000	0.000		
Age	Year	-0.001	0.000	-1.00	0.315
Gender		0.000	0.000	0.00	1.000
Marital Status		0.000	0.000	0.00	1.000
Education	Year	0.000	0.000	0.00	1.000
Income	Year	0.000	0.000	0.00	1.000
Health		0.000	0.000	0.00	1.000
Religion		0.000	0.000	0.00	1.000
Occupation		0.000	0.000	0.00	1.000
Region		0.000	0.000	0.00	1.000
Time	Year	0.000	0.000	0.00	1.000
Constant		1.000	0.000		

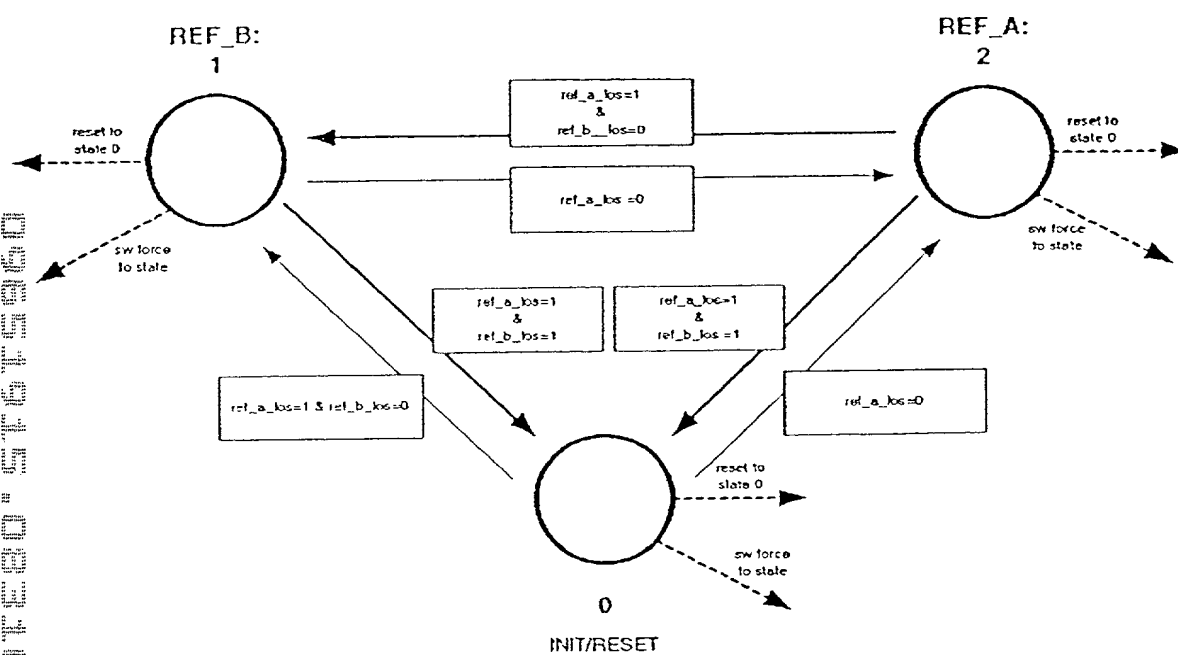


FIG. 48

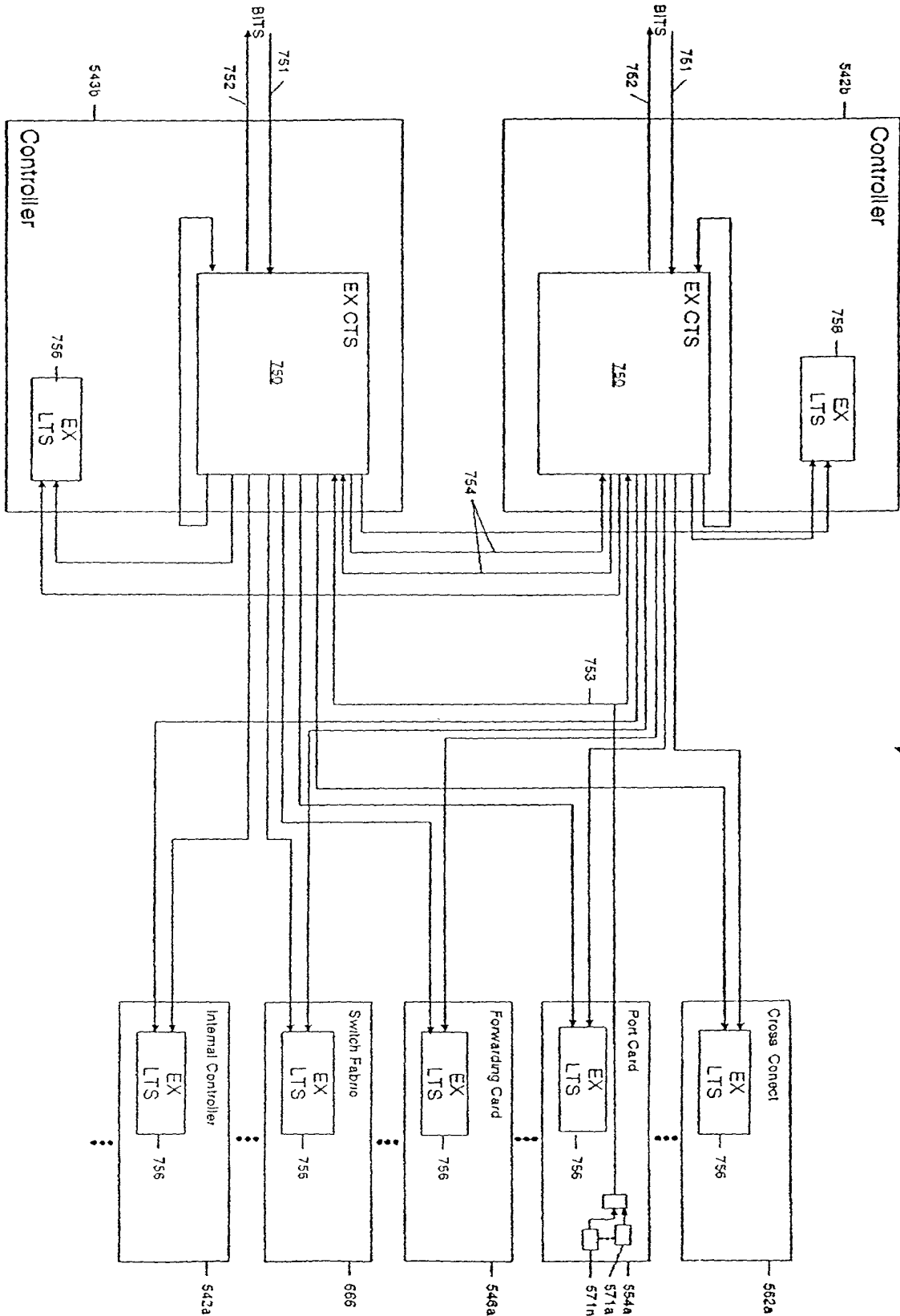
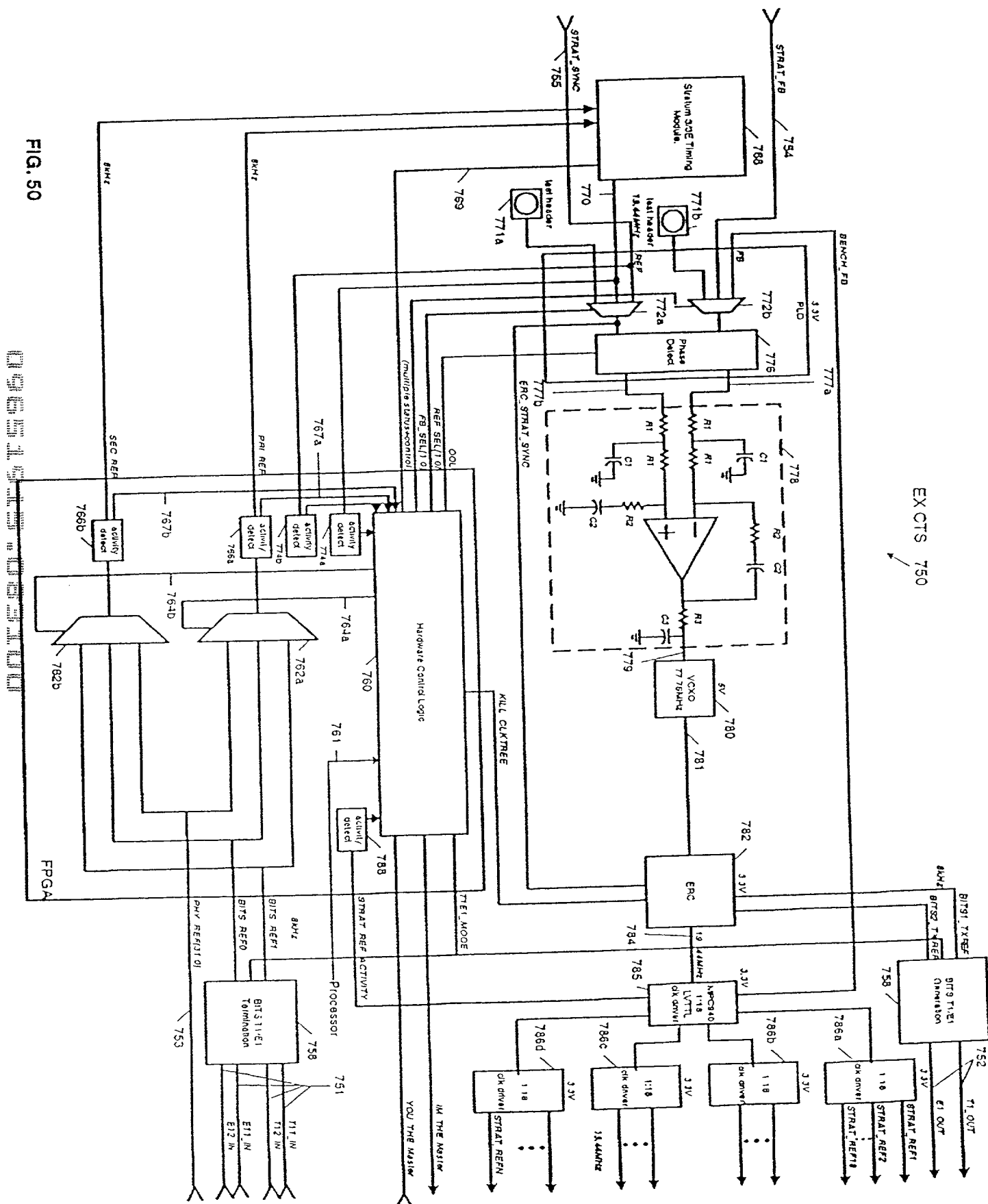


FIG. 49

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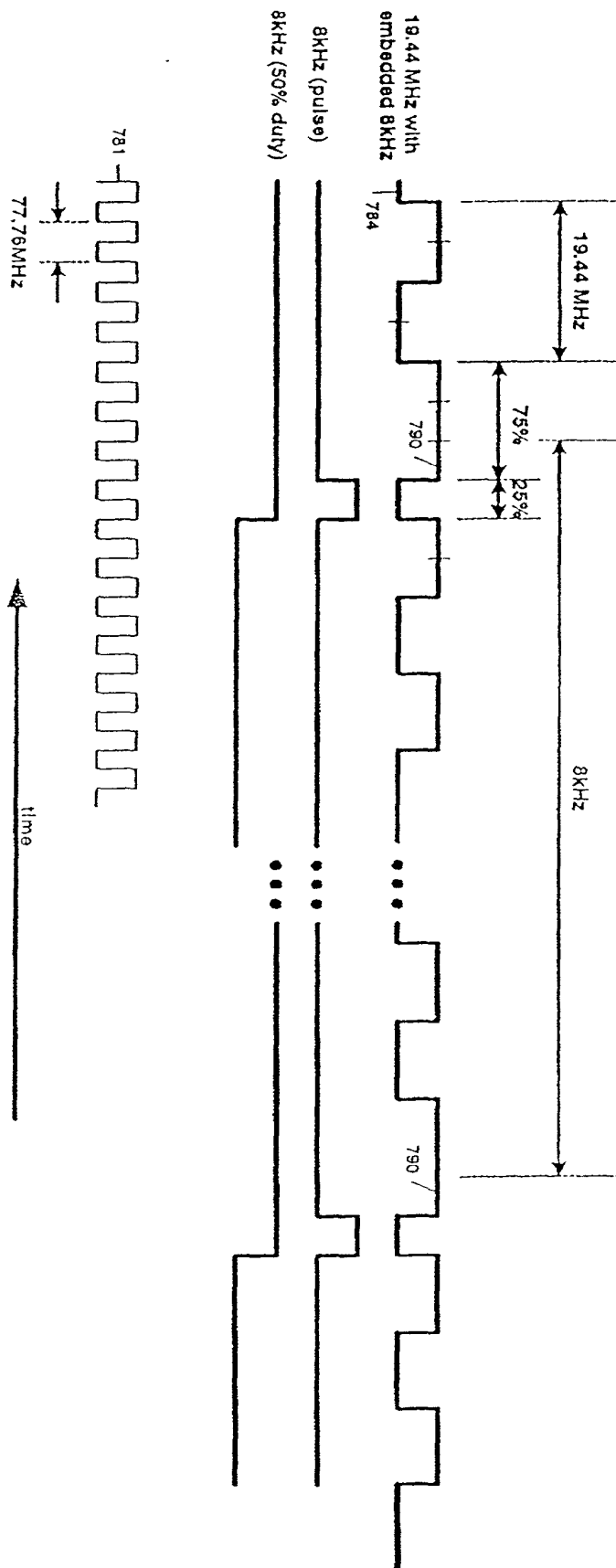


FIG. 51

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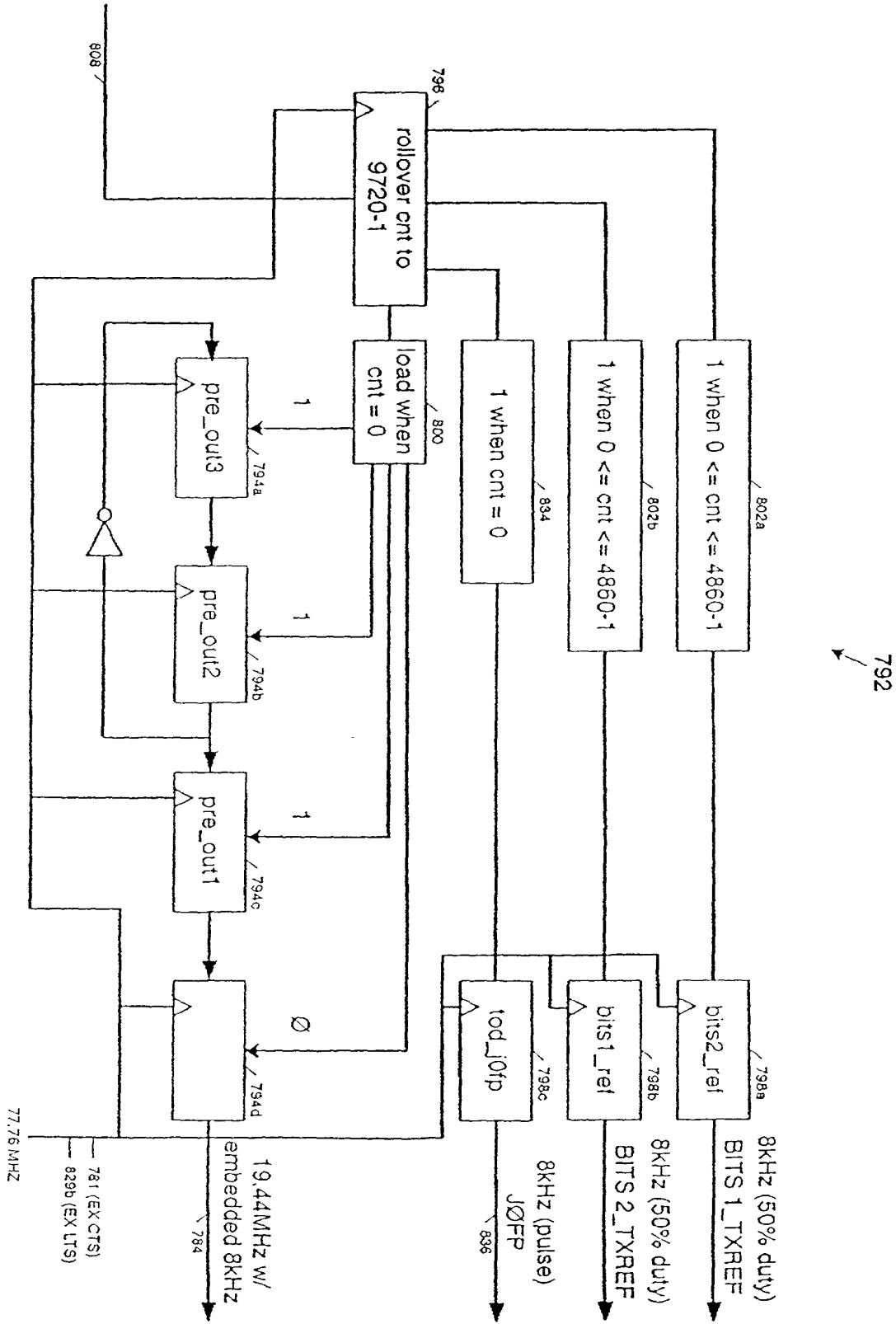
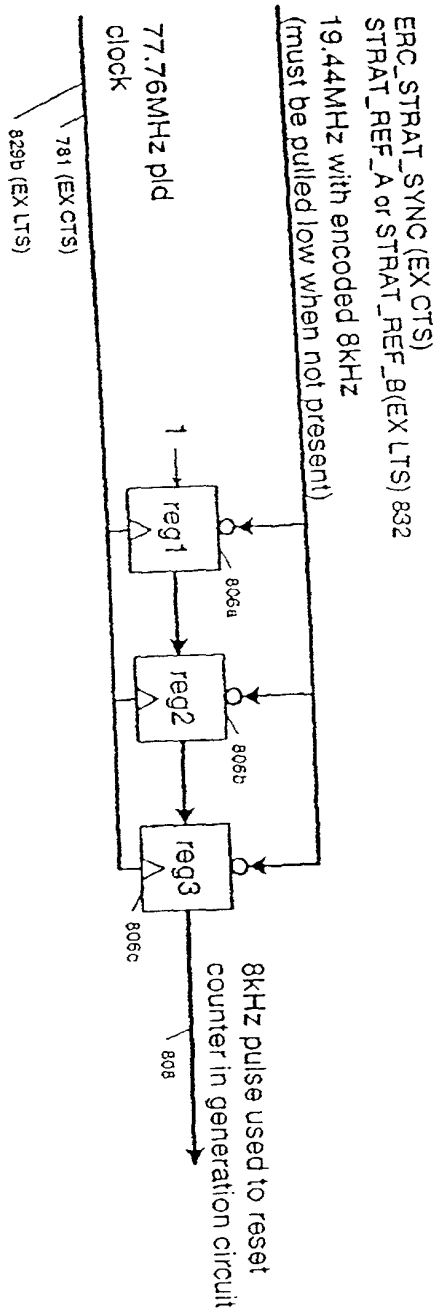


Fig. 52

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804

Extractor

FIG. 53

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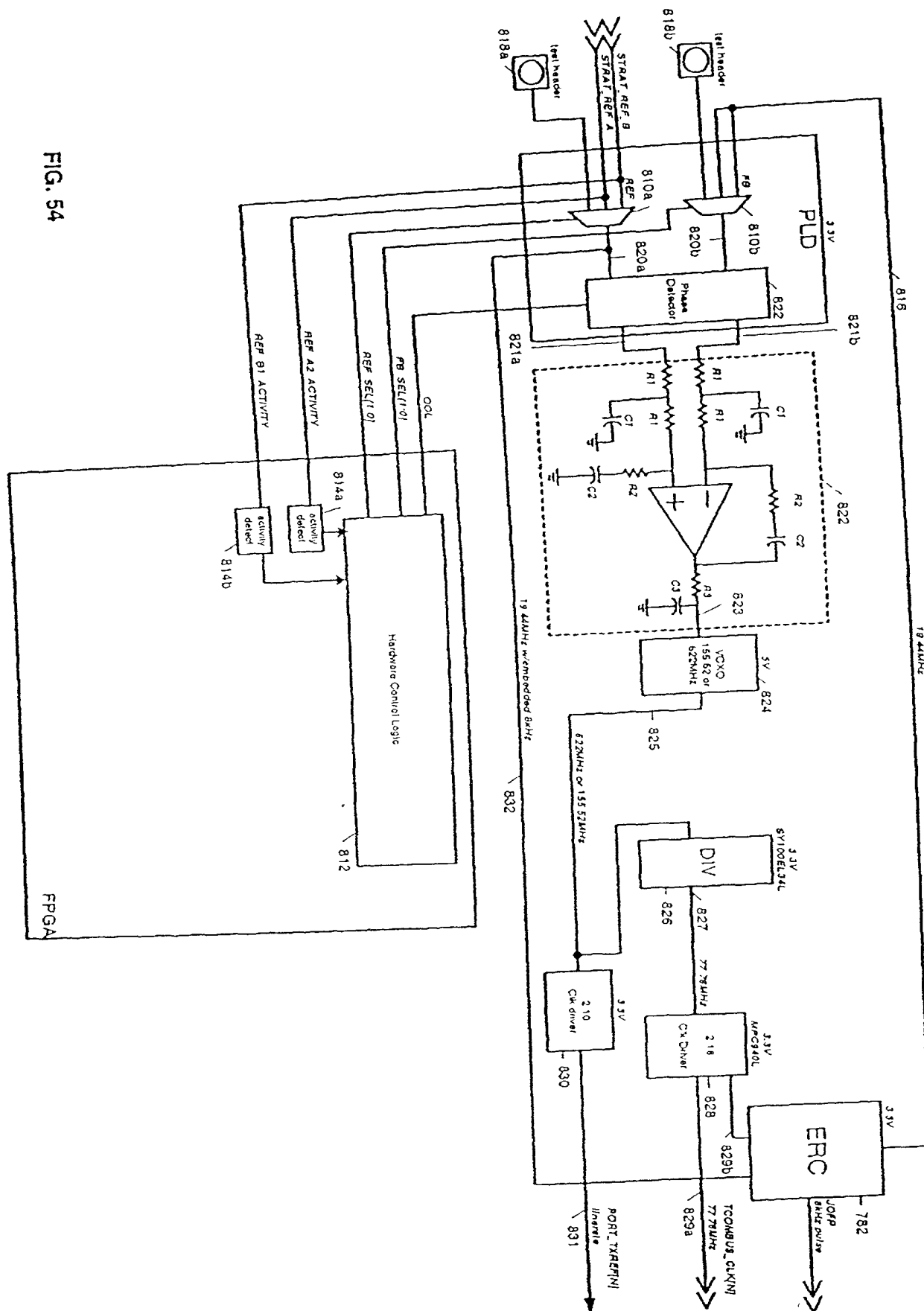


FIG. 54

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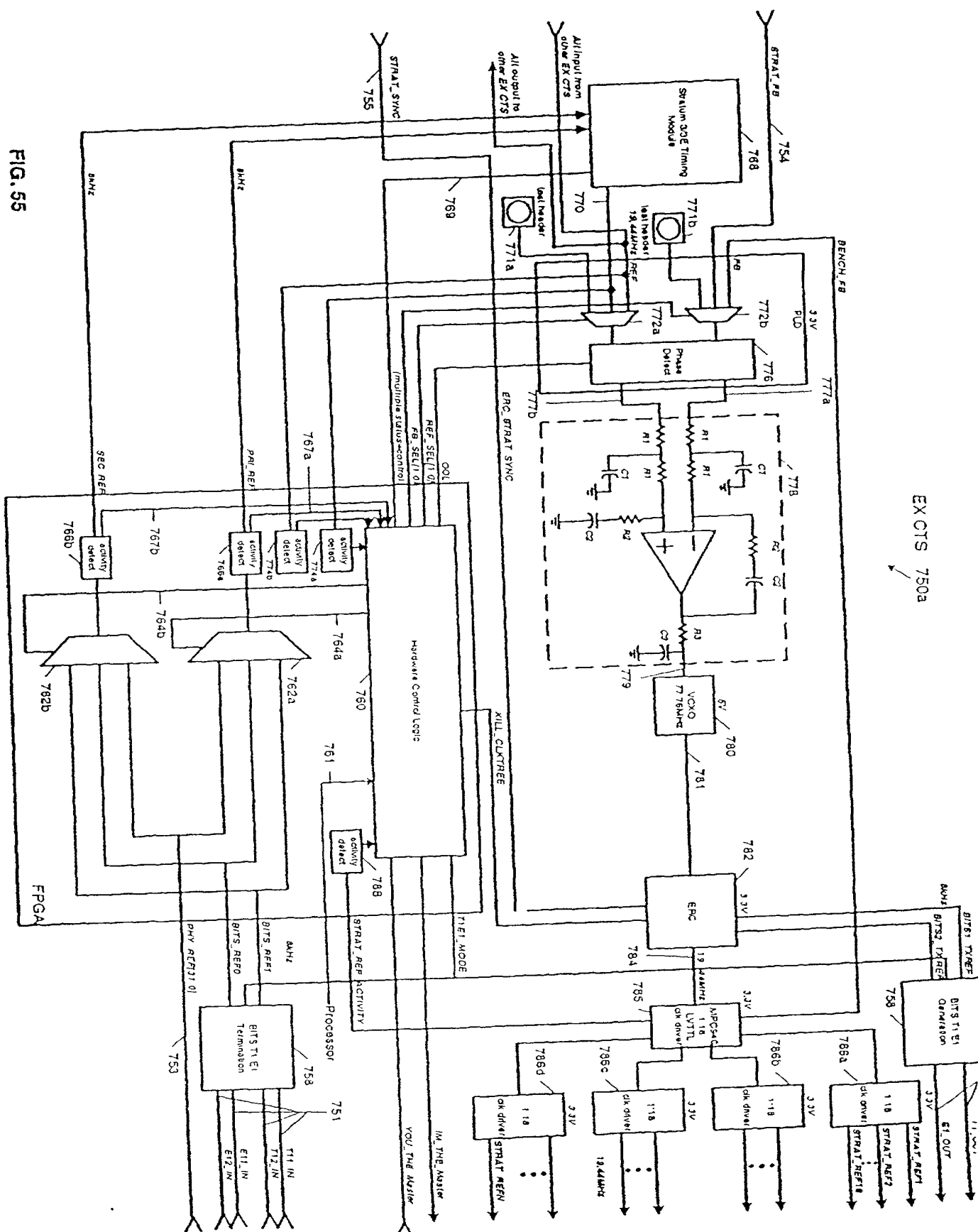


FIG. 55

Parameter	Control		Fertilizer		Fertilizer + PGR		Fertilizer + PGR + GA	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Plant height (cm)	100.0	1.5	100.0	1.5	100.0	1.5	100.0	1.5
Stem diameter (mm)	10.0	0.2	10.0	0.2	10.0	0.2	10.0	0.2
Root length (cm)	15.0	0.5	15.0	0.5	15.0	0.5	15.0	0.5
Root diameter (mm)	2.0	0.1	2.0	0.1	2.0	0.1	2.0	0.1
Stem diameter at 10 cm (mm)	10.0	0.2	10.0	0.2	10.0	0.2	10.0	0.2
Stem diameter at 20 cm (mm)	10.0	0.2	10.0	0.2	10.0	0.2	10.0	0.2
Stem diameter at 30 cm (mm)	10.0	0.2	10.0	0.2	10.0	0.2	10.0	0.2
Stem diameter at 40 cm (mm)	10.0	0.2	10.0	0.2	10.0	0.2	10.0	0.2
Stem diameter at 50 cm (mm)	10.0	0.2	10.0	0.2	10.0	0.2	10.0	0.2
Stem diameter at 60 cm (mm)	10.0	0.2	10.0	0.2	10.0	0.2	10.0	0.2
Stem diameter at 70 cm (mm)	10.0	0.2	10.0	0.2	10.0	0.2	10.0	0.2
Stem diameter at 80 cm (mm)	10.0	0.2	10.0	0.2	10.0	0.2	10.0	0.2
Stem diameter at 90 cm (mm)	10.0	0.2	10.0	0.2	10.0	0.2	10.0	0.2
Stem diameter at 100 cm (mm)	10.0	0.2	10.0	0.2	10.0	0.2	10.0	0.2
Stem diameter at 110 cm (mm)	10.0	0.2	10.0	0.2	10.0	0.2	10.0	0.2
Stem diameter at 120 cm (mm)	10.0	0.2	10.0	0.2	10.0	0.2	10.0	0.2
Stem diameter at 130 cm (mm)	10.0	0.2	10.0	0.2	10.0	0.2	10.0	0.2
Stem diameter at 140 cm (mm)	10.0	0.2	10.0	0.2	10.0	0.2	10.0	0.2
Stem diameter at 150 cm (mm)	10.0	0.2	10.0	0.2	10.0	0.2	10.0	0.2
Stem diameter at 160 cm (mm)	10.0	0.2	10.0	0.2	10.0	0.2	10.0	0.2
Stem diameter at 170 cm (mm)	10.0	0.2	10.0	0.2	10.0	0.2	10.0	0.2
Stem diameter at 180 cm (mm)	10.0	0.2	10.0	0.2	10.0	0.2	10.0	0.2
Stem diameter at 190 cm (mm)	10.0	0.2	10.0	0.2	10.0	0.2	10.0	0.2
Stem diameter at 200 cm (mm)	10.0	0.2	10.0	0.2	10.0	0.2	10.0	0.2
Stem diameter at 210 cm (mm)	10.0	0.2	10.0	0.2	10.0	0.2	10.0	0.2
Stem diameter at 220 cm (mm)	10.0	0.2	10.0	0.2	10.0	0.2	10.0	0.2
Stem diameter at 230 cm (mm)	10.0	0.2	10.0	0.2	10.0	0.2	10.0	0.2
Stem diameter at 240 cm (mm)	10.0	0.2	10.0	0.2	10.0	0.2	10.0	0.2
Stem diameter at 250 cm (mm)	10.0	0.2	10.0	0.2	10.0	0.2	10.0	0.2
Stem diameter at 260 cm (mm)	10.0	0.2	10.0	0.2	10.0	0.2	10.0	0.2
Stem diameter at 270 cm (mm)	10.0	0.2	10.0	0.2	10.0	0.2	10.0	0.2
Stem diameter at 280 cm (mm)	10.0	0.2	10.0	0.2	10.0	0.2	10.0	0.2
Stem diameter at 290 cm (mm)	10.0	0.2	10.0	0.2	10.0	0.2	10.0	0.2
Stem diameter at 300 cm (mm)	10.0	0.2	10.0	0.2	10.0	0.2	10.0	0.2
Stem diameter at 310 cm (mm)	10.0	0.2	10.0	0.2	10.0	0.2	10.0	0.2
Stem diameter at 320 cm (mm)	10.0	0.2	10.0	0.2	10.0	0.2	10.0	0.2
Stem diameter at 330 cm (mm)	10.0	0.2	10.0	0.2	10.0	0.2	10.0	0.2
Stem diameter at 340 cm (mm)	10.0	0.2	10.0	0.2	10.0	0.2	10.0	0.2
Stem diameter at 350 cm (mm)	10.0	0.2	10.0	0.2	10.0	0.2	10.0	0.2
Stem diameter at 360 cm (mm)	10.0	0.2	10.0	0.2	10.0	0.2	10.	

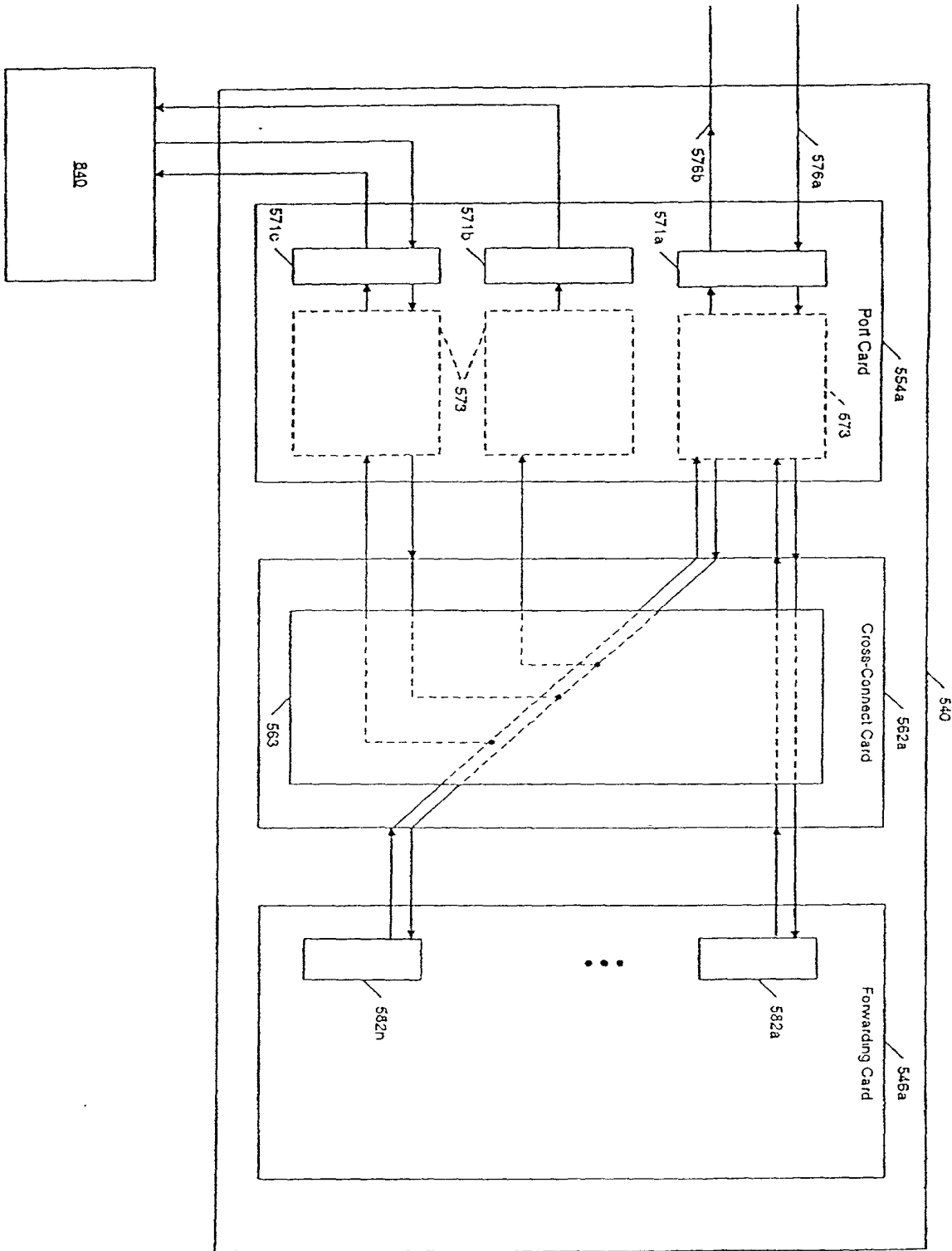
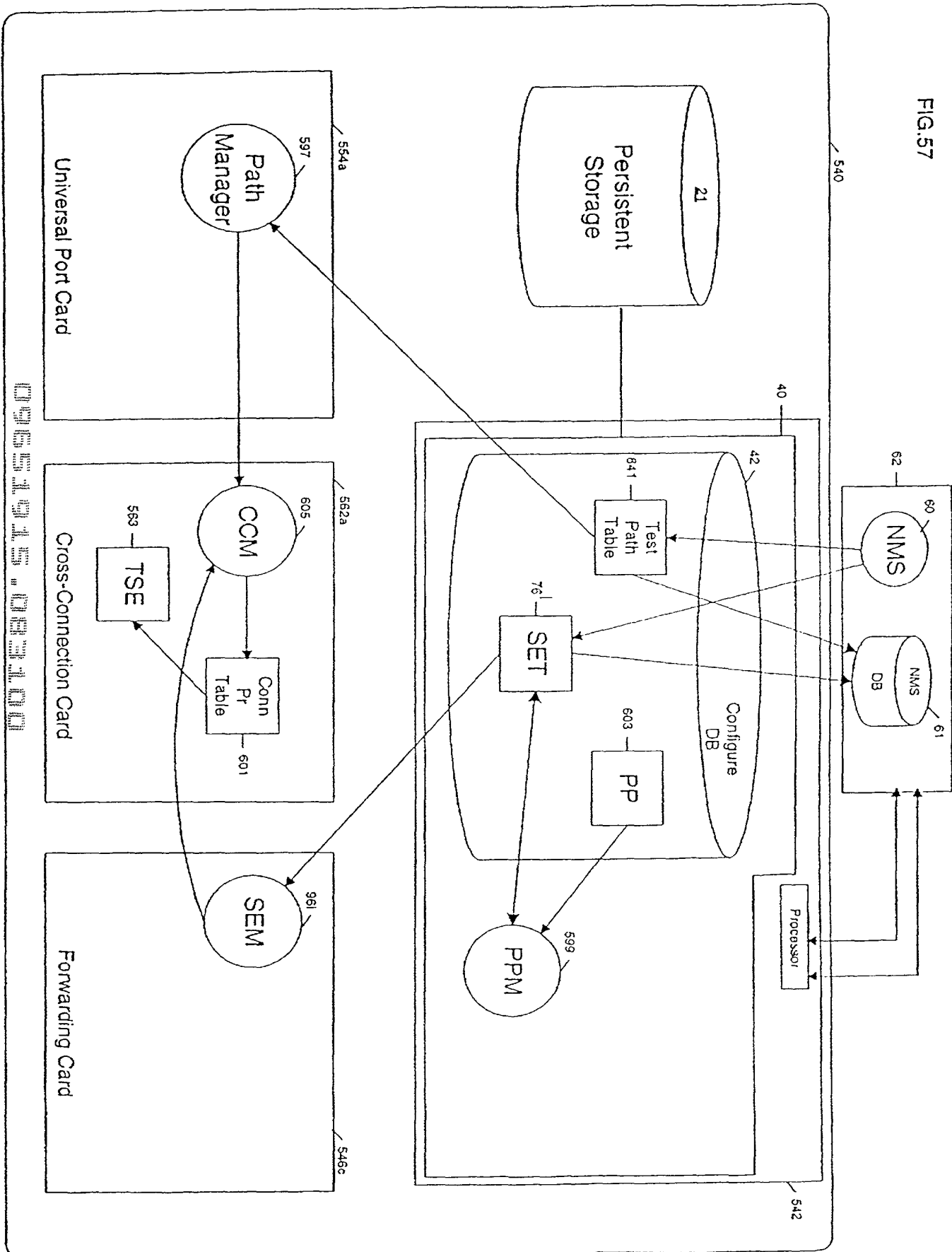


Fig. 56

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FIG. 57



	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100
0	0.0000	0.0001	0.0002	0.0003	0.0004	0.0005	0.0006	0.0007	0.0008	0.0009	0.0010	0.0011	0.0012	0.0013	0.0014	0.0015	0.0016	0.0017	0.0018	0.0019	0.0020	0.0021	0.0022	0.0023	0.0024	0.0025	0.0026	0.0027	0.0028	0.0029	0.0030	0.0031	0.0032	0.0033	0.0034	0.0035	0.0036	0.0037	0.0038	0.0039	0.0040	0.0041	0.0042	0.0043	0.0044	0.0045	0.0046	0.0047	0.0048	0.0049	0.0050	0.0051	0.0052	0.0053	0.0054	0.0055	0.0056	0.0057	0.0058	0.0059	0.0060	0.0061	0.0062	0.0063	0.0064	0.0065	0.0066	0.0067	0.0068	0.0069	0.0070	0.0071	0.0072	0.0073	0.0074	0.0075	0.0076	0.0077	0.0078	0.0079	0.0080	0.0081	0.0082	0.0083	0.0084	0.0085	0.0086	0.0087	0.0088	0.0089	0.0090	0.0091	0.0092	0.0093	0.0094	0.0095	0.0096	0.0097	0.0098	0.0099	0.0100

FIG. 58

Test Path Table 841

844						845
Path LID	UP Port LID	Time Slot	# of Time Slots	Monitor	Enable Port Receiver	...
842 — 1666	1232	4	3	Ingress	No	
843 — 1666	1233	4	3	Egress	No	
844 — 1666	1233	4	3	Ingress	Yes	
...	...	...	...			...

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EXPRESS MAILING LABEL NO.: EL327517295US

Attorney Docket No.: 102689-51/00-U0075

**DECLARATION AND POWER OF ATTORNEY FOR  
UNITED STATES LETTERS PATENT APPLICATION**

As a below-named inventor, I hereby declare that:

My residence, post-office address and citizenship are as stated below next to my name.

I believe I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled:

**NETWORK MANAGEMENT SYSTEM INCLUDING CUSTOM SCREEN MARKS**

the specification of which

(check one)

☒ is attached hereto.

☐ was filed on

as Application No.:

and was amended on:  
(if applicable).

In the event that the filing date and/or Application No. are not entered above at the time I execute this document, and if such information is deemed necessary, I hereby authorize and request my attorneys/agent(s) at Nutter, McClennen & Fish, LLP, One International Place, Boston, MA 02110-2699, to insert above the filing date and/or Application No. of said application.

I hereby state that I have reviewed and understand the contents of the above-identified application specification, including the claims, as amended by any amendment specifically referred to herein.

I acknowledge the duty to disclose all information known to me that is material to patentability in accordance with Title 37, Code of Federal Regulations, § 1.56.

09651915.083400

## FOREIGN PRIORITY CLAIM

I hereby claim foreign priority benefits under Title 35, United States Code §119(a)-(d) of any foreign application(s) for patent or inventor's certificate listed below and have also identified below any foreign application for patent or inventor's certificate having a filing date before that of the application on which priority is claimed:

(check one)

☒ no such foreign applications have been filed.

☐ such foreign applications have been filed as follows:

EARLIEST FOREIGN APPLICATION(S), IF ANY FILED WITHIN 12 MONTHS  
(6 MONTHS FOR DESIGN) PRIOR TO THIS U.S. APPLICATION

Country	Application Number	Date of Filing (month, day, year)	Priority Claimed Under 35 USC 119
			___ Yes No ___
			___ Yes No ___
			___ Yes No ___
			___ Yes No ___
			___ Yes No ___

ALL FOREIGN APPLICATION(S), IF ANY FILED MORE THAN 12 MONTHS  
(6 MONTHS FOR DESIGN) PRIOR TO THIS U.S. APPLICATION


**CLAIM FOR BENEFIT OF EARLIER U.S. PROVISIONAL APPLICATION(s)**

I hereby claim priority benefits under Title 35, United States Code §119(e), of any United States provisional patent application(s) listed below:

(check one)

- ☒ no such U.S. provisional applications have been filed.
- ☐ such U.S. provisional applications have been filed as follows:

Application Number	Date of Filing (month, day, year)	Priority Claimed Under 35 USC 119(e)
		___ Yes No ___
		___ Yes No ___
		___ Yes No ___

**CLAIM FOR BENEFIT OF EARLIER U.S./PCT APPLICATION(s)**

I hereby claim the benefit under Title 35, United States Code §120, of the United States application(s) listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States application in the manner provided by the first paragraph of Title 35, United States Code, §112, I acknowledge the duty to disclose all information that is material to patentability in accordance with Title 37, Code of Federal Regulations, §1.56, and which became available to me between the filing date of the prior application and the national or PCT international filing date of this application:

(check one)

- ☐ no such U.S./PCT applications have been filed.
- ☒ such U.S./PCT applications have been filed as follows:

Application Number	Date of Filing (month, day, year)	Status (Patented/Pending/Abandoned)
Integrating Operations Support Services With Network Management Systems	August 7, 2000	Pending

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment or both under Section 1001 of Title 18 of the United States

Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

I hereby appoint:

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all of Nutter McClennen & Fish, LLP, One International Place, Boston, Massachusetts 02110-2699, jointly, and each of them severally, my attorneys at law/patent agent(s), with full power of substitution, delegation and revocation, to prosecute this application, to make alterations and amendments therein, to receive the patent, and to transact all business in the Patent and Trademark Office connected therewith.

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